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TUNGSTEN ORES

BY

R. H. RASTALL, M.A., F.G.S.

UNIVERSITY LECTURER IN ECONOMIC GEOLOGY, CAMBRIDGE

AND

W. H. WILCOCKSON, M.A., F.G.S.

LECTURER IN GEOLOGY, UNIVERSITY OF SHEFFIELD

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PREFACE

THE Mineral Resources Committee of the Imperial Institute has arranged for the issue of this series of Monographs on Mineral Resources in amplification and extension of those which have appeared in the *Bulletin* of the Imperial Institute during the past fifteen years.

The Monographs are prepared either by members of the Scientific and Technical Staff of the Imperial Institute, or by external contributors, to whom have been available the statistical and other special information relating to mineral resources collected and arranged at the Imperial Institute.

The object of these Monographs is to give a general account of the occurrences and commercial utilisations of the more important minerals, particularly in the British Empire. No attempt has been made to give details of mining or metallurgical processes.

HARCOURT,
Chairman, Mineral Resources Committee.

December, 1919.

CONTENTS

CHAPTER I

CHAPTER II

CHAPTER III

NOTE:—*Numerals in square brackets in the text refer to the Bibliography at the end.*

TUNGSTEN ORES

CHAPTER I

TUNGSTEN ORES: THEIR OCCURRENCE, CHARACTERS AND USES

INTRODUCTION

ONE of the remarkable effects of the war on mining and metallurgy was the development of a keen interest in the tungsten industry. The demand for tungsten for munition-making soon grew insistent; production of the ores became very active in many countries; prices soared to an abnormal height, and the market was only steadied by prompt Government action in fixing prices and in taking measures to stimulate production and to control export. Although a great part of the world's supply of ore is derived from British and United States territory, before the war the metallurgical treatment was almost entirely in German hands, and most of the ore was exported to Germany. In 1912 and 1913 the imports of tungsten concentrates into that country were 4,130 and 4,494 tons respectively, while the export of tungsten metal was about 800 tons.[1] Since in modern British practice 1 ton of metal is obtainable from 2 tons of concentrates, it is evident that a large balance of metal remained in Germany. However, it is clear that after the beginning of the war German stocks soon ran short, and vigorous efforts were made to obtain supplies from neutral countries, especially from Spain and America. The requirements of the Allies were also very great, and it soon became necessary to undertake the metallurgical treat-
England. The situation
tively. The metallurgy of

[1] The statistics throughout this Monograph are official, except where otherwise stated.

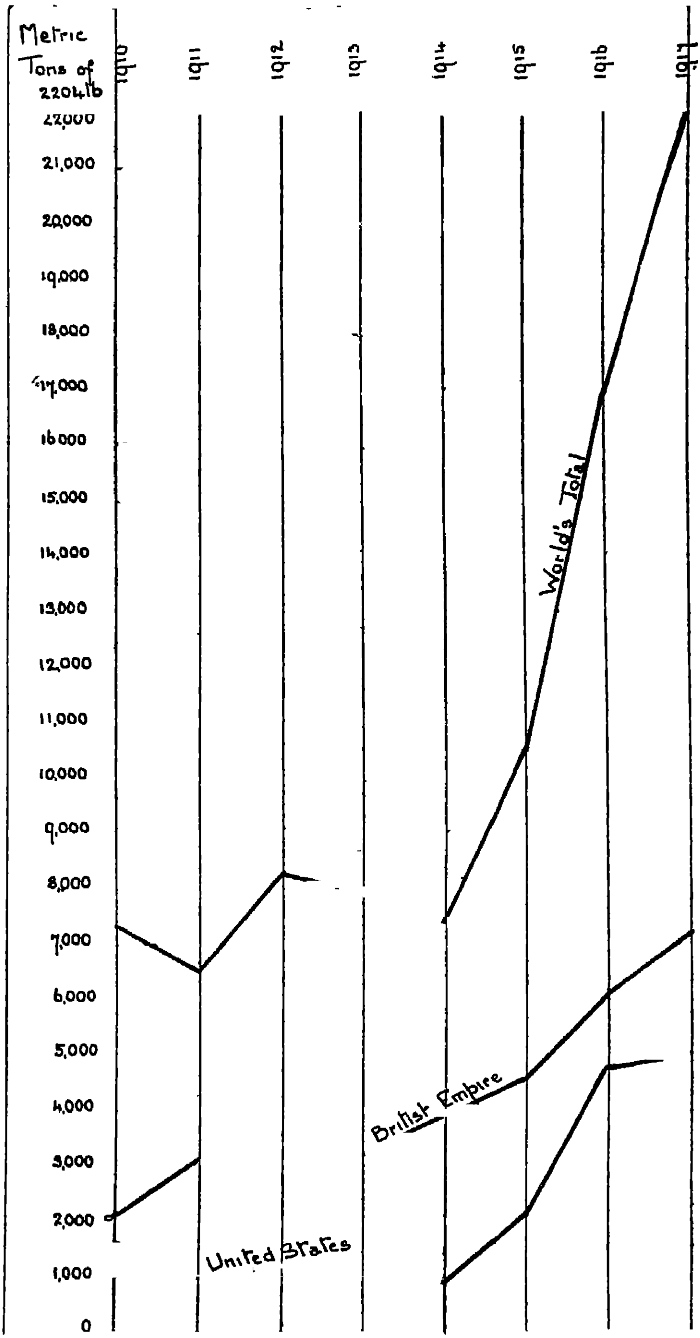

DIAGRAM I.—WORLD'S OUTPUT OF TUNGSTEN ORES SHOWN IN COMPARISON WITH OUTPUT OF BRITISH EMPIRE AND UNITED STATES, 1910–1917.

British hands, export of the ore beyond the limits of the Empire being prohibited, and sales controlled by the Governments concerned.

WORLD'S PRODUCTION

The world's production of tungsten ores for the period 1910 to 1917 is shown in the following table:

In metric tons (2,204 lb.)

—	1910.	1911.	1912.	1913	1914	1915.	1916.	1917.
British countries:								
[1] United Kingdom	278	270	196	185	209	336	400	245
[2] Burma . .	402	1,352	1,699	1,715	2,364	2,689	3,710	4,553
[3] Malay States .	—	188	323	324	436	457	839	1,200*
[4] New South Wales	321	398	231	173	200	84	268	249
[5] Queensland † .	908	684	831	549	443	662	515	502
[6] Tasmania . .	68	71	68	69	48	97	108	245
[7] New Zealand .	145	140	137	225	208	196	270	164
[8] *Foreign countries:*								
Germany, Austria . .	60	145	167	150*	220*	250*	300*	250*
France. . .	30	146	230	245*	200*	200*	200*	225*
Spain . . .	153	96	169	150	84	511	651	800*
Portugal . .	948	903	1,330	800	967	933	1,418	1,596
Japan . . .	250	261	205	297	195	439	1,150*	1,500*
China . . .	—	—	—	—	—	—	—	1,200
Siam . . .	—	—	108	281	30	297	468	634
United States .	1,652	1,033	1,207	1,395	898	2,116	4,719	5,000*
Argentina . .	1,912	584	638	539	394	171	700*	1,000*
Bolivia . .	207	297	497	564	276	793	920*	1,650*
Peru . . .	12	48	214	300	196	371	400*	1,000*

* Estimated.
† Including the following amounts of mixed bismuth and wolfram:

1910.	1911	1912.	1913.	1914	1915.	1916.	1917.
35	131	194	185	196	251	139	133

[1] *Mines and Quarries Reports.* [2] *Geological Survey of India.*
[3] *Mines Statements.* [4] *Mines Department Reports.*
[5] *Mines Department Reports.* [6] *Mines Department Reports.*
[7] *New Zealand—Mines Statements.*
[8] *Mineral Industry* and *U.S Statistical Abstract.*

The diagrams on pages 2 and 4 show (1) the outputs of the British Empire and the United States, the two chief producers, in comparison with the world's output; and (2) the comparison of the outputs of the chief producing countries.

As appears from the table, the chief producing countries

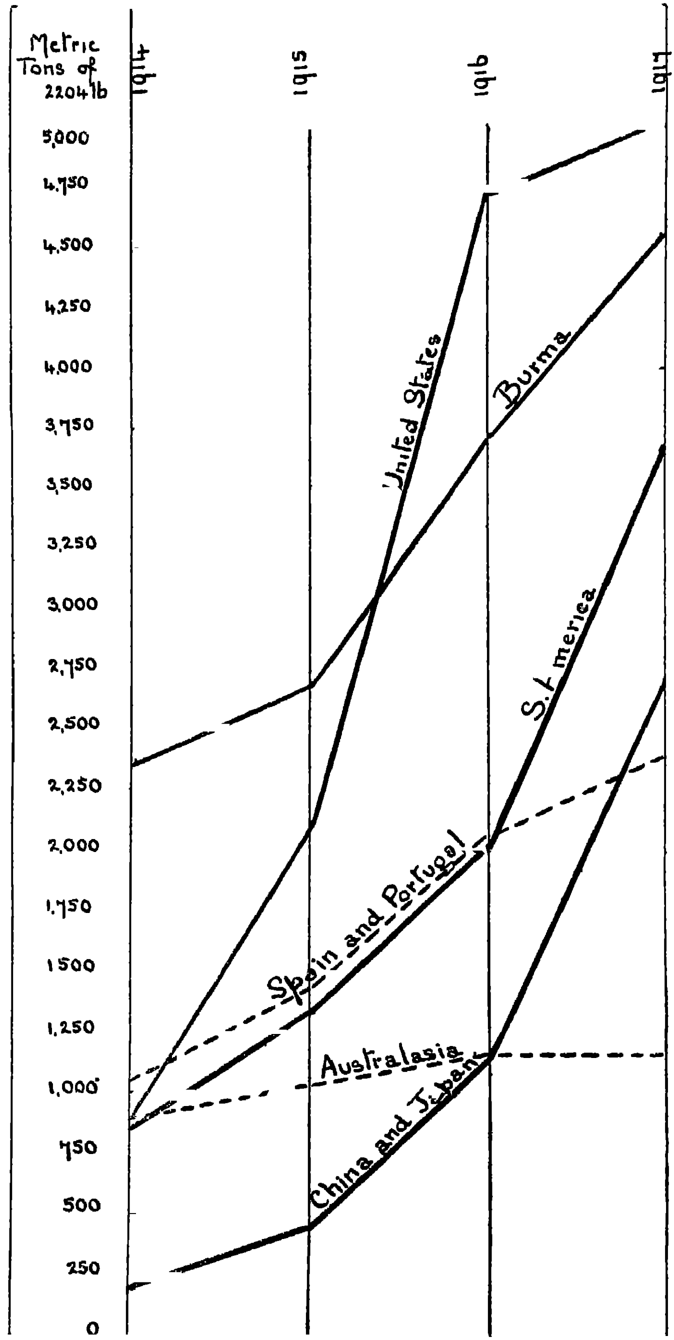

DIAGRAM 2.—PRODUCTION OF TUNGSTEN ORES IN CHIEF PRODUCING COUNTRIES, 1914–1917.

are the United States and Burma, which between them accounted for over 50 per cent. of the world's supply in 1917. It also appears that the British Empire possesses very large resources, more than enough to supply its own needs, leaving a good deal available for export.

With regard to the question of reserves, it is very difficult to form an opinion of any value. The occurrence of tungsten ores is always irregular, and little is known as to the laws governing their persistence in depth; the occurrence of the ores in the lodes is nearly always sporadic, so that the mining and the estimation of reserves are rather irregular and unreliable. In consequence of this the mining has till recently been for the most part in the hands of a large number of small syndicates or single owners, who have followed rich ore shoots and neglected the lower grade ores. Till the beginning of the war-boom tungsten mining was not a very attractive proposition for large capitalists, and even yet it is in rather a precarious position. There is now, however, a strong tendency for the amalgamation of small concerns or absorption by powerful companies, which will in the future greatly increase efficiency and economy of working. Even yet, in some districts controlled by large companies, the tribute system prevails, with bad results. Owing to the urgent demand many mines have in the last two or three years been worked in an improvident manner, without proper regard for future development, and some districts are already showing signs of exhaustion. In other parts of the world, for example in China, there still appear to be vast supplies as yet hardly touched, and it seems probable that sufficient tungsten ore will be available to meet all demands for many years to come.

Tungsten Minerals

The only tungsten minerals of any economic importance are the tungstates of iron, manganese and calcium. These may be divided according to their crystal form into two natural groups: the iron and manganese tungstates form the wolfram group, crystallizing in the monoclinic system, while calcium tungstate, scheelite, belongs to the tetragonal system.

The pure iron tungstate, $FeWO_4$, is known as ferberite, and the pure manganese tungstate, $MnWO_4$, as hübnerite. Wolfram, or wolframite, is commonly a mixture of these two compounds in varying proportions. The following classification has been proposed by Messrs. Hess and Schaller of the United States Geological Survey [1]. All varieties containing 80 per cent. or more of the iron molecule are called ferberite, and all those with over 80 per cent. of the manganese molecule are hübnerite, while the intermediate members of the series are known as wolframite. However, for practical purposes the distinction is unimportant, and the whole series is here called wolfram, the ordinary miner's term, in preference to the perhaps more strictly scientific names proposed by the authors quoted.

Wolfram sometimes occurs in well-formed prismatic or tabular crystals, as for example in Colorado, but more commonly in columnar, blade-like or massive forms; it possesses one very perfect cleavage, which causes it to break up readily into thin flakes. The hardness is about 5 and the specific gravity varies from 7 2 to 7 5. The colour is nearly black, the varieties rich in manganese having a brownish tinge. Most varieties are sufficiently magnetic to be attracted by an electro-magnet, which facilitates separation from cassiterite.

Scheelite, as before stated, is calcium tungstate, $CaWO_4$. Most samples show, on analysis, 2 or 3 per cent. of molybdenum, replacing part of the tungsten. Well-developed crystals are usually double tetragonal pyramids, but the mineral more often occurs in a massive form with four good cleavages; the hardness varies from 4 to 5, and the specific gravity is about 6. This latter property serves to distinguish scheelite from most other minerals of similar appearance, while it also greatly facilitates mechanical separation. The colour is variable; generally grey, pale yellow or pale brown, rarely green or reddish, with a curious waxy lustre.

The other minerals containing tungsten are of little or no practical importance. The principal ores are stolzite, $PbWO_4$, cuprotungstite, $CuWO_4$, and chillagite [2], a mixture of lead tungstate and lead molybdate, found in Queensland.

Crystals of wolfram and scheelite in lodes and other deposits sometimes undergo a slight amount of decomposition, becoming covered with a bright yellow powder, known as tungstite or tungstic ochre, probably a hydrated form of tungsten trioxide. This cannot be regarded as an important ore, owing to its very small quantity in most cases. It is recorded that half a carload was once shipped from a mine in British Columbia, but this appears to be an isolated instance.

THE GENESIS OF TUNGSTEN ORES

From the genetic point of view the tungsten ores can be divided into two groups, primary and secondary [3]. The primary group includes the lodes, veins, dykes, and contact deposits, while the secondary group comprises all the numerous varieties of alluvial and residual deposits. The primary ores are nearly always in close association with granites, and are often accompanied by tin. The tungsten is derived from the granite magma, having been concentrated in the last portions to solidify, and carried to the margin of the intrusion and beyond as some volatile compound, possibly the fluoride. Thus the behaviour of tungsten is very like that of tin, but it appears that tungsten compounds can travel farther than tin compounds; thus the tungsten zone is often found above the tin zone. In some places wolfram is found without tin, but there is always the possibility that it may be succeeded by tin either in depth, or nearer the granite [4]

Wolfram occurs normally either disseminated through granite, or concentrated in pegmatites, dykes and quartz veins, the latter often being continuations of pegmatites, and therefore of direct igneous origin. It also occurs to a large extent in the country rock adjoining the veins, many lodes being actually zones of rock impregnated with ores derived from vapours or solutions passing through cracks due to contraction or faulting. When calcareous rocks are acted on in a similar way scheelite is formed.

It is quite clear that the deposition of the ores took place during the later stages of the cooling of the granite, after the partly solidified rock had begun to crack, and the vapours

were escaping from the still hot interior, where the constituents of lowest freezing-point tend to concentrate. Hence the genesis of primary tungsten ores is clearly a case of magmatic differentiation by fractional crystallization. At the same time the contact deposits, especially certain masses of scheelite, were formed by the action of escaping gases and solutions on calcareous rocks. It is usually stated that wolfram is of later formation than cassiterite, when the two minerals occur together, but Dr. Morrow Campbell [135] has brought forward evidence to show that in Burma the wolfram is of earlier formation than the tin ore. On this point further information from other localities is desirable.

It is unnecessary to describe in detail the formation of secondary tungsten deposits. The laws governing the weathering of tungsten ores are at present rather obscure, and in need of investigation [136] Under some conditions of climate wolfram seems readily to undergo decomposition, but in other cases it acts as a stable mineral and accumulates in detrital deposits like tinstone, gold and platinum.

Mining and Concentration of Tungsten Ores

The winning of tungsten ores does not present any special peculiarities, but follows the methods commonly adopted for other ores of a similar nature, both lodes and alluvial deposits. A large proportion of the world's supply of wolfram is found in association with tinstone, and the same methods are applied to both, so that any description of the methods of mining and concentrating tinstone will apply almost equally well to tungsten. From some districts the mixed tinstone and tungsten concentrates are shipped without further separation, but more commonly some form of magnetic separator is employed. Wolfram is fairly magnetic, since it contains a good deal of iron, while tinstone is not attracted as a rule even by powerful electro-magnets [5] Scheelite, however, contains no iron, and can only be separated from tin by chemical methods, such as fusion with sodium carbonate. Fortunately, however, the association of tinstone with scheelite is not common. In localities such as Colorado and Argentina,

where tinstone is not found, the practice is much the same as in tin-mines, except that magnetic separation is usually unnecessary.

It is highly desirable that tungsten concentrates should be as pure as possible. The theoretical percentage of tungsten trioxide in wolfram is about 76, in scheelite about 80; and in some cases, as in Australia, concentrates are produced containing as much as 72 per cent. But on the average the percentage is about 65, and any proportion below this is usually penalised in the selling price.

Valuation and Price

The value of tungsten ores is always calculated on assay (chemical analysis), the price being quoted at so much per unit, that is, 1 per cent. of tungsten trioxide in the concentrate. The analysis of good quality samples usually shows from 60 to 70 per cent. tungsten trioxide and in this country 65 per cent. is adopted as a standard, in the United States 60 per cent. is the usual figure. An excessive amount of certain impurities, such as phosphorus and arsenic, is usually penalised in the price. Before the war the usual price was from 25*s*. to 35*s*. per unit; in order to steady the market, the price was fixed by agreement with the trade in June 1915 at 55*s*. per unit. Afterwards this was confirmed by the British and Dominion Governments, and it so remained until January 1918, when it was raised to 60*s*., with special allowances in certain cases for high freights and loss on exchange. In America, where the price was not controlled, it rose abnormally, and it is reported that as much as 120 dollars per unit was paid at one time; for 60 per cent. concentrates this works out to about £1,400 per ton. It is also believed that the German Government paid enormous prices for tungsten ores, to be shipped by submarine or otherwise smuggled into the country.

Metallurgy of Tungsten

For the preparation of metallic tungsten from the ores on a large scale two types of process are now in use, namely, reduction by carbon and the Thermit process.

The treatment adopted at the works of the High Speed Steel Alloys, Co., Ltd., at Widnes, may be summarized very briefly as follows [6]. The concentrate as received from the mines is crushed finer if necessary, and passed through a magnetic separator to eliminate tinstone and other deleterious impurities. It is then mixed with excess of sodium carbonate, and heated to about 1,000° C. in a reverberatory furnace. The product is broken up small in a ball-mill, passed through a fine mesh, and leached in boiling water; the solution is then treated with strong hydrochloric acid and the precipitate dried in centrifugal driers. It is then in the form of tungsten trioxide. This is mixed with anthracite and roasted in a crucible in an open furnace, thus being reduced to metal; when cool the mass is ground to powder, washed, dried and packed in tin cases. The final product contains about 98·5 per cent. of tungsten metal, and 0·2 per cent. of carbon. It is found that 2 tons of concentrates make 1 ton of metal, and the plant capacity in 1916 was about 3 tons of metal per day.

The Thermo-electric Ore Reduction Corporation, Ltd., of Luton, uses a process similar to the above for metal, and also manufactures ferrotungsten by electric furnace treatment. Several other British firms also produce both the metal and ferrotungsten.

The metal produced by the method above described is in the form of a powder; for the manufacture of high-speed steel and other alloys it is used in this state, but for most other purposes the solid metal is required. In a general way ductile tungsten is made as follows. The powder is squeezed in a hydraulic press into bars, which are just coherent enough to be handled. These are next heated to a very high temperature in a furnace, after which the solidified metal is hammered, rolled, punched and drawn as required. As a result of this treatment tungsten becomes ductile, and can be drawn into wire having a diameter as small as 0·0006 inch, such as is used in the filaments of electric lamps. The final drawing is effected by means of diamond dies. Tungsten wire has also been made by squirting processes.

For the manufacture of ferro-tungsten three types of process are employed, namely, direct reduction of the ore by carbon

in a crucible in a combustion furnace, reduction by carbon in the electric furnace, or alumino-thermic methods. The first two processes give a product with high carbon, needing further refining, while the last gives a product with much less carbon.

In the reduction process as employed by the Bierman Company of Hanover, the fine ore is mixed with iron oxide, wood charcoal, powdered glass and quartz, while sometimes tar or rosin is added [7].

The manufacture of ferro-tungsten in the electric furnace, as carried out by the Tungsten Products Co. at Boulder, Colorado, gives a product containing about 85 per cent. tungsten with carbon below 0·5 per cent. The charge is mixed in the proportion of 200 lb. concentrate, 42 lb. coke, 56 lb. lime, and 6 lb. fluorspar. After fusion the mass contains about 3 per cent. carbon. It is then broken up and refined by fusion with more concentrate, which diminishes the amount of carbon [8].

The following are analyses of typical samples of ferro-tungsten:

	Per cent.	Per cent.	Per cent.	Per cent.
Tungsten	85·15	74·19	72·09	71·50
Carbon	0·45	1·00	0·96	0·88
Silicon	0·13	0·39	0·76	0·70
Manganese	0·085	0·53	0·24	0·21
Phosphorus	0·018	0·010	0·055	0·039
Sulphur	0·21	0·013	0·037	0·022

Utilisation of Tungsten

Although the metal tungsten and many of its compounds have long been known, their technical and commercial application are of comparatively recent development. From the middle of last century onwards sodium tungstate was used to a limited extent as a mordant in dyeing, and for rendering textile fabrics more or less incombustible. The remarkable effects of the addition of the metal to steel were brought into prominence by Robert Mushet of Sheffield in 1857, and his steel, which contained from 6 to 8 per cent. of tungsten, was made by Samuel Osborn & Co. of Sheffield for cutting tools of various kinds. Steel made in America by the Taylor-White process was shown at the Paris Exhibition of 1900,

but the patents were held to be invalid, as the same process had long been used in England [9]. About the year 1905 a demand sprang up for the metal for the filaments of electric lamps, and the manufacture of tungsten steel for high-speed tools soon after became of great importance. The outbreak of war in 1914 led to an enormous increase in the demand for this alloy for munition making. The amount of high-speed steel made in this country during 1918 was about 20,000 tons; this needs about 3,000 tons of metallic tungsten, or its equivalent in ferro-tungsten.

High-speed steel is used for engineers' tools, such as turning, planing and slotting tools, twist-drills, reamers, taps and screwing dies, metal-milling cutters, cold-iron saws and shell-making tools, also for valves in motor and aeroplane engines, and for parts of magnetos [10]. The value of such steel produced during 1918 in the British Empire was estimated at £7,500,000, at war prices.

The special properties of high-speed steel are hardness and tensile strength, which are retained at high temperatures, almost up to red heat. The addition of 20 or 30 per cent. of tungsten to steel increases these properties, while additional hardness is given by a smaller proportion of chromium and vanadium. The following are analyses of typical British high-speed steels [11].

	Carbon.	Tungsten.	Chromium.	Vanadium.
A	0·58	17·4	3·11	1·14
B	0·60	13·3	3·32	3·58
C	0·53	13 0	4·69	2·45
D	0·75	17·7	3·30	0·85
E	0·60	16·5	3·55	0·70

Some foreign makers employ a considerably higher proportion of tungsten and chromium, as shown by the following analyses:

	Carbon.	Tungsten.	Chromium.
French	0·90	22·80	8·10
Austrian	0·93	24·50	7·19
German	0·60	30·20	3·70

An analysis of another German sample showed the presence of 4 per cent. of cobalt and nearly 1 per cent. of molybdenum, in addition to chromium and vanadium.

For ordinary cutting tools, such as knives and saws, a much smaller proportion of tungsten is used, generally about 4 per cent., while a spring-steel may have as little as 0·6 per cent [12].

Tungsten may be added to the steel either as the pure metal or as ferro-tungsten. For high-tungsten steels most makers prefer the metal, as it introduces less impurity. For lower grades ferro-tungsten is usually employed, and some makers prefer it for the manufacture of even high-tungsten steels in the electric furnace.

Besides the uses enumerated above tungsten is also employed as a constituent of a variety of alloys for special purposes, since it possesses a remarkable property of hardening other metals besides iron. *Stellite* is an alloy of 65 per cent. cobalt, 15 per cent. chromium, and 20 per cent. tungsten, and it is stated to be superior to tungsten steel for cutting tools, saws and knives. It is also used for surgical instruments since it is not affected by organic acids or by the ordinary antiseptics; it is, however, attacked by mineral acids and by fused alkalies. Stellite is extremely hard, and takes a good polish; it is stiffer than steel of the same section, but the elastic limit is not quite so high [13]. *Amaloy* is a somewhat similar alloy of nickel, chromium and tungsten, which is very serviceable for relay contacts in railway signals and for surgical and dental instruments. Tungsten is also a constituent of certain alloys highly resistant to acids, which can be used for many purposes as a substitute for platinum [14]. The ternary nickel-copper-tungsten alloys of this type are greatly improved by the addition of a small quantity of iron. The following composition gives very satisfactory results: copper 43·65 per cent., nickel 50·58 per cent., tungsten 3·90 per cent., iron 1·87 per cent. This is practically unattacked by boiling concentrated sulphuric acid. The addition of about 1 per cent. of tungsten to aluminium-cobalt alloys with 10 per cent. of cobalt increases the tensile strength threefold [15]. *Platinoid* is an alloy of 60 per cent. copper, 25 per cent. zinc, 14 per cent. nickel, and 1 per cent. tungsten, which can also be used for many purposes as a substitute for platinum.

Owing to its high melting-point, greater conductivity, hardness and cheapness, tungsten is held to be superior to platinum for much electrical work, and it is used for the contacts of voltage regulators, in railway signal relays, in telephone jacks, for spark-coil contacts, for magneto circuit-breaker contacts, for spark plugs and as a winding for electric furnaces, in which it enables a higher temperature to be obtained, though an atmosphere of hydrogen is rendered necessary. The points enumerated above, combined with its low volatility and high specific gravity, render tungsten of great value for the targets of X-ray tubes. Its high specific gravity gives great penetrating power to the rays, while its high thermal conductivity and melting-point enable it to be placed exactly at the focus of the cathode rays, instead of just outside, as is the case with platinum targets, and so to increase the sharpness of the shadowgraph. The most important electrical use of the metal, however, is for the filaments of electric glow-lamps. For this purpose tungsten has entirely replaced tantalum owing to its greater tensile strength and higher efficiency, the efficiency of a drawn wire tungsten lamp being 1.1 watts per candle power as against 1·7 watts per candle power in the case of the tantalum lamp A further lowering of current consumption to 0·5 watts per candle power in the case of high-power lamps has been obtained by filling the bulbs with an atmosphere of nitrogen.

Metallic tungsten is also used for the poles of various forms of arc lamps enclosed in bulbs either exhausted or filled with inert gas, as an example of which the " Pointolite " lamp introduced in 1916 by Messrs. Edison and Swan may be quoted.

Tungsten trioxide forms, with potassium and sodium, certain peculiar compounds known as " tungsten bronzes," which are used for decorative purposes [16]. They are prepared by fusing the calculated quantities of tungstic acid with the carbonates of the metals and electrolysing the mass. The compound $Na_5W_6O_{18}$ is golden yellow, $Na_2W_5O_{15}$ is blue, $Na_2W_3O_9$ is red, while blue tungsten-lithium bronzes are also known. Magenta bronze is a potassium compound, $K_2W_4O_{12}$.

Tungsten trioxide is also used for imparting a yellow colour to glass and porcelain.

CHAPTER II

SOURCES OF SUPPLY OF TUNGSTEN ORES

(*a*) BRITISH EMPIRE

THE figures for the output of tungsten ores in different parts of the British Empire are given in the world's production table on p. 3. The diagram on page 16 shows the comparative importance of the different parts of the Empire in tungsten-ore production.

EUROPE

UNITED KINGDOM

CORNWALL AND DEVONSHIRE.—Nearly all the tungsten ores of the British Isles are obtained from Cornwall and the neighbouring part of Devonshire Five principal producing districts may be distinguished, each being in close connection with a mass of granite; they are as follows, from west to east: (1) Land's End, (2) Camborne and Redruth, (3) St. Austell, (4) Bodmin Moor, (5) Hingston Down and Callington. These districts are of very unequal importance, the Land's End area being mainly of historical and theoretical interest. From most of them small quantities of scheelite have been recorded, but the chief ore is wolfram.

It is unnecessary to describe in detail the geology of the region. The country rock, usually called killas, is composed of altered slaty sediments ranging in age from Lower Palæozoic or older to Devonian and Carboniferous; all these are penetrated by great masses of granite and by quartz-porphyry dykes known as elvans, by pegmatites and by quartz veins. There are also some greenstone sills of unknown age. The lodes carrying wolfram are nearly always situated near the junction of the granite and killas [17]. As already pointed out, there is a close genetic connection between ores of tungsten and of tin, and in general terms it may be stated that in

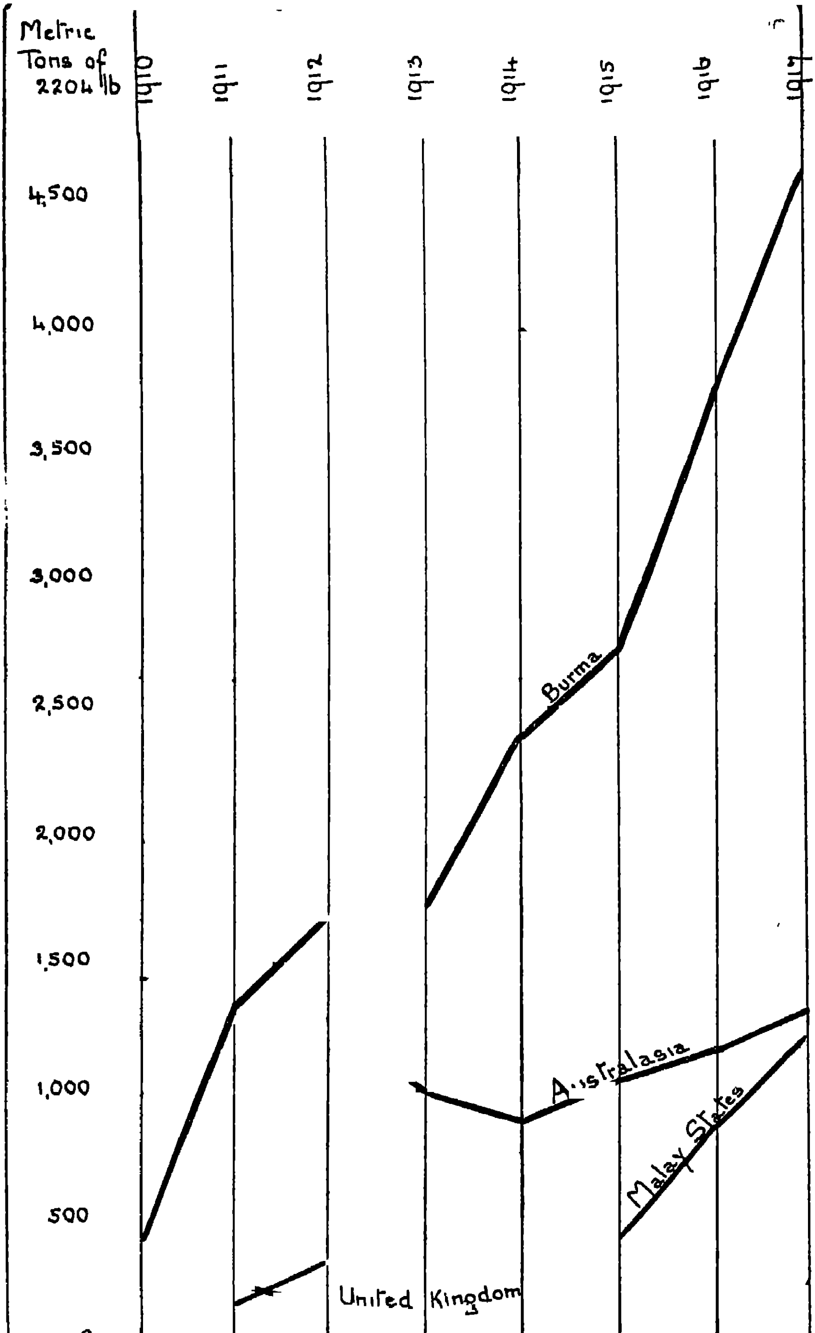

DIAGRAM 3.—OUTPUT OF TUNGSTEN ORES IN BRITISH COUNTRIES, 1910–1917.

Cornwall wolfram is most abundant in the upper part of the tin zone and below the rich copper zone. Another very common associate is mispickel. A good deal of wolfram has also been obtained from alluvial and other secondary deposits [18].

(1) *Land's End District.*—Both wolfram and scheelite have been recorded from certain mines in this district, especially from Levant and Botallack in the parish of St. Just, while the occurrence in the granite and greisen of St. Michael's Mount is of great theoretical interest: none of these seem to be of any practical importance [19].

(2) *Camborne and Redruth.*—The most important wolfram-producing area in Cornwall is the highly mineralized zone that skirts the north-western margin of the Carn Brea granite. Here are situated a large number of famous tin and copper mines, such as Dolcoath, Carn Brea, Tincroft, South Crofty, East Pool and Agar, most of which are now producing a considerable amount of wolfram, while others are in course of development for that purpose. The number and variety of ores and other minerals found in this area are very great, the most important being ores of tin, copper, tungsten and arsenic, with smaller amounts of silver, lead, zinc, bismuth, cobalt, nickel, molybdenum, manganese, iron and uranium [20].

The lodes, which as a rule strike about E. 20° N., are very numerous, being mostly in close connection with the contact of granite and killas: the underlie is in different directions in different lodes, but the richest lodes dip to the north. Much confusion has been caused by the application of varying names to parts of the same lode; for example, the Burncoose lode of Carn Brea is the same as the North Tincroft and East Pool lode and the North Entral lode of Dolcoath, and so on. As is well known, the upper parts of the lodes are rich in copper, giving place to tin below, at a level depending on the depth of the granite margin. The principal lodes intersect the granite as well as the killas, and the richest deposits of wolfram ore are generally found within 50 or 60 feet of the contact, that is at depths ranging from 900 to 1,200 feet from the surface. When the lodes are clean and well-defined, the wolfram usually occurs with tinstone and quartz next to the walls, with the sulphides and other minerals of later date in the middle.

The great lodes of South Crofty and East Pool consist mainly of friction-breccias, infiltrated and altered by mineralizing solutions, thus forming an interlacing network of veins enclosing fragments of country rock, and the whole lode often shows no definite boundary.

The geology of the East Pool mine has been very fully described by Dr. Maclaren [21]. The lodes lie in killas and in granite, forming three series, according to the direction of underlie. The most important group dip to the north, including the South Lode and its faulted continuation in depth, the Great Lode, while the newly discovered Rogers Lode is a downward prolongation of the Dobree or North Lodes on the footwall side of a greenstone sill. The south-dipping group includes the New North Lode, the New Engine Lode and others. The vertical lodes are of less importance. The minerals of these lodes include cassiterite, wolfram, chalcopyrite, mispickel, bismuthinite, azurite, stannite, scheelite, fluorspar and some cobalt ores. In the Rogers Lode secondary scheelite has been observed in cracks and veins in the wolfram. The wolfram zone occurs near the top of the tin zone, in the Great Lode from 140 to 196 fathoms; in one place it formed a solid mass 4 feet thick.

The Rogers Lode was discovered in 1913 by a cross-cut on the 160 fathom level, and has proved a regular bonanza; it yields values up to 130 lb. of mixed tin and wolfram concentrates per ton over a width varying from 4 to 6 feet, while in one place as much as 336 lb. per ton was obtained over a width of 10 ft. Development is now in rapid progress. The other important mines of this group are South Crofty and Tincroft, which is now amalgamated with Carn Brea. These are so similar in their general characters that no good purpose would be served by describing them in detail. The following table, taken from the published reports of the companies, shows the output of wolfram from the mines of this group for the years 1914–16 (long tons):

	1914	1915.	1916.
East Pool and Agar .	107·0	127·0	100·5
South Crofty . . .	113·2	97·5	95·4
Tincroft	19·0	39·8	43·3
Total . .	239·2	264·3	239·2

The North Gorland mine, near St. Day, 1¼ miles from Scorrier station, also lies on the junction of granite and killas. The main lode strikes E 40° N, and dips north; it is about 8 feet wide and yields about 1 per cent. of tin and wolfram. A second rich lode, striking east and west, has not been much worked. In the six years 1906–11 this mine yielded 208 tons of 65 per cent. concentrates, but was closed in 1912.

At the Park-an-chy mine, also near Scorrier station, the country rock consists of slates and tourmaline granite. The Main Lode, which is nearly vertical, with a slight underlie to the north, bears mainly wolfram in quartz and fluorspar, yielding from 14 to 28 lb., and locally 40 lb., of concentrates per ton. This mine was recently reopened with Government assistance, but the working does not appear to have been successful [22].

The Peevor United Mines, 1½ miles north of Redruth station, possess several lodes striking E 30° N., which carry a fair amount of wolfram on the eastern side of a cross-course fault and some wolfram has also been found in the dumps.

In the *Geological Survey Memoir* on this district [20] it is recorded that wolfram has been obtained from Balmynheer, in the parish of Wendron, at Wheal Harmony, north of Redruth, at Wheal Busy, Wheal Friendship in Gwennap, at Penzilly in Breage and at Poldice. Most of these mines are now closed.

(3) *St. Austell.*—In this district wolfram is known to occur to a considerable extent in lodes along with tin and other minerals of the ordinary type [23]. The Wheal Bunny mine is situated in a china-clay district east of Hensbarrow Beacon. The main lode, which here has a width of some 20 feet, consists of numerous alternating bands of kaolinized granite, greisen and quartz, the latter containing tinstone, wolfram and iron ore, with a little copper. The total output of wolfram for the years 1903–7 is stated to have been 82 tons. The North Bunny lodes are very similar, and also contain a little wolfram. In the Great Beam mine there are three lodes very like those of Wheal Bunny, but somewhat wider, containing

the same minerals. The Maudlin mine has yielded copper, tin, wolfram and scheelite, but the quantities are not stated. Wolfram also occurs to a considerable extent in veins in the granite of Cligga Head, near Perranporth, with tinstone, copper ore and molybdenite, but the distribution is very sporadic [24].

The most important producer of this area at the present time is the Castle-an-Dinas mine, recently purchased by South Crofty [25]. It lies on Goss Moor, north-west of St. Austell, 3 miles from St. Columb and Roche stations. Development began in February 1917, and 400 tons of ore yielded 10 tons of wolfram concentrates with 65 per cent. tungsten trioxide and only 0·25 per cent. of tin. The ground developed averages 30 lb. of wolfram per ton over a width of 3 feet and at least 11,000 tons of ore are in sight.

(4) *Bodmin Moor.*—Wolfram has long been known to exist in the alluvial deposits of Bodmin Moor, and more recently a considerable number of lodes have been found [23]. Several mines in the area are now producing on a considerable scale. The Treburland mine in the parish of Altarnun, 7 miles S.W. of Launceston, is situated at the junction of granite and killas. Two of the lodes carry wolfram, associated with tin and mispickel, and yield about 40 lb. of wolfram per ton. Wheal Vincent, also in the parish of Altarnun, 9 miles from Launceston, lies in granite which is highly mineralized along fissures, and encloses veins of pegmatite and quartz; wolfram also occurs as an original mineral in the granite and in large crystals in the pegmatites. There are five chief lodes; the principal one, the Horseburrow lode, is 4 feet wide, and is rich in wolfram. At Cannaframe the granite is traversed by pegmatites rich in wolfram, with tin and copper, and also by lodes exceptionally rich in wolfram. The Halvana mine comprises six lodes, all dipping south, in granite with pegmatite, aplite and greisen. The Gazeland mine in the parish of St. Neot, 3 miles from Doublebois station, shows several lodes in killas, striking east and west; some of them contain wolfram, with a rather patchy distribution. All the foregoing mines produced ore in 1917.

A large proportion of the tin and wolfram of the Bodmin Moor district has been obtained from superficial (secondary) deposits of various kinds, especially from the stream gravels and the "head" of Bodmin Moor itself. The superficial deposits lying above the 750-foot contour line differ markedly in character from those below that level [26]. The high-level deposits consist mainly of pebbles of much decomposed granite, with tin and wolfram, largely covered by peat; these masses of "head" were formed during the glacial period while the subsoil was frozen, so that surface water had full play; consequently they are often very coarse in texture. An example is afforded by the Buttern Hill wolfram deposit which lies in Bowithick Marsh, south of Davidstow, near Altarnun. This deposit, which is about 6 feet thick in the middle, lies in a hollow, running up a hill, and has been worked in terraces. Wolfram was here found to be so abundant that tin working was stopped for many years. It is a curious fact that the local veins contain no tin. Kenton Marsh is a somewhat similar tract of water-logged ground, partly streamed for tin, but containing a good deal of ore in 1908. At Nine Stones Marsh gravel is worked by hydraulicking.

The stream-tin gravels proper, lying at lower levels, have been formed in the ordinary way by river action; many of them seem to date from a time when the land stood higher than now, relatively to the sea. The tin ground is usually at the base of the gravels, sometimes 40 or 50 feet below the present surface, and in places a certain amount of wolfram is found along with it.

(5) *Callington and Tavistock.*—Wolfram and scheelite also occur to a considerable extent in the neighbourhood of Callington in Cornwall and Tavistock in Devonshire. The principal mines are near Kit Hill and Gunnislake, Hingston Downs and Gunnislake Clitters. Old Gunnislake and Hawkmoor have now been amalgamated into a single concern, with an area of about 1,200 acres. Several lodes are known near the margin of granite and slate; they run up to 20 feet in width, and carry some 3 per cent. of tin and wolfram together with a little arsenic and copper. One lode in the Clitters mine

gave assays up to 7 per cent. From 1903 to 1909 the mines of this group are said to have yielded 564 tons of wolfram, and they are again producing a considerable amount. The Dimson mine, near New Bridge, Gunnislake, is in granite with east and west lodes and cross courses running north and south, both containing wolfram. At Kit Hill there are several lodes running east and west, with tin, wolfram, copper and mispickel. East Kit Hill mine is in altered Devonian slates, traversed by the same lodes as at Kit Hill. On the Devonshire side of the river Tamar ore is obtained from the Bedford United mine, while the Devon Friendship mine near Marytavy yields scheelite and cassiterite with chalybite and dolomite. In this region the Duchy of Cornwall has recently done a good deal of prospecting by trenching the surface, resulting in the discovery of several lodes. It is also understood that a good deal of tungsten ore is now being produced at the Hemerdon mine, near Plympton; the mineral occurs in small veins, and is disseminated through decomposed granite; a considerable quantity of ore has been developed, and it is anticipated that this mine will become one of the principal producers in the country.

CUMBERLAND.—The only other British locality where tungsten ores are known to occur is at Carrock Fell in Cumberland, on the north-eastern side of the Skiddaw massif, and 7 miles from Troutbeck station on the Cockermouth, Keswick and Penrith railway. The country rock consists of highly metamorphosed Skiddaw slate, greisen and gabbro, cut by several quartz veins from 3 to 4 feet wide, having a general north and south strike. These veins appear to be offshoots of the Skiddaw granite, and contain a considerable variety of minerals, including scheelite, wolfram, mispickel, with some galena, blende, and bismuth minerals, together with oxidation products of the sulphides; one small vein contains molybdenite [27]. Three lodes are now being worked, but the Harding vein, lying in greisen and gabbro, is the main source of output. At present the working is only on a small scale, the yield for six months being 41 tons of concentrates containing about 38 per cent. of tungsten trioxide. The large proportion of mispickel is somewhat

detrimental, but an increased output of tungsten ore is expected in the near future.

ASIA

India

Burma.—Lower Burma and the Malay Peninsula, together with the intervening Siamese territory, belong to a single geological structural unit, forming the innermost zone of the great folded Malayan arc. The Palæozoic and older rocks of this area were in late Jurassic or Cretaceous times strongly folded and faulted, the disturbance being accompanied by the intrusion of great masses of granite [28]. It was at this time that the mineralization took place, but the present disposition of the rocks is due to Tertiary earth-movements. In Burma the strike is more or less north and south, but in the Malay States it swings round to a N.W.–S.E. direction. The same general structure can be traced into Sumatra and the Dutch islands of Banka and Billiton. The prevailing strike of the folded rocks likewise determines the direction of the principal lodes and cross-courses. Throughout the whole belt of country, about 1,000 miles long, extending from the Southern Shan States to Singapore, ores of tin and tungsten occur; in the south tin is dominant, in the north tungsten. It has been suggested by Dr. W. R. Jones that this difference is due to the amount of denudation undergone by each district, this being greater in the south; hence it is possible that the wolfram lodes of Burma may pass down into tin lodes in depth, whereas in the Malay States the upper wolfram zone has already been for the most part weathered away, leaving the rich tin zone exposed at the surface [4]

The development of the tungsten industry in Burma has been extraordinarily rapid. In 1909 the output was only 7 tons; in 1916 it was 3,761 tons, valued at £460,000, while the output for 1917 is estimated at over 4,500 tons. For the years 1912–15 Burma headed the list of producing countries, but was afterwards surpassed by the United States. The following table shows the production for the years 1912–17 inclusive:

Production of Tungsten Ore in Burma and India

In long tons (2,240 lb)

	1912.	1913.	1914.	1915.	1916.	1917.
Burma:						
Mergui	218	206	194	232	340	368
Tavoy	1,393	1,399	1,977	2,033	3,034	3,697
Southern Shan States	60	84	138	331	185	307
Thaton	—	—	17	49	92	108
India:						
Marwar	—	—	—	—	33	42
Singhbhum	—	—	—	—	8	20
Nagpur	0·2	—	—	—	1·3	—
Total	1,671	1,689	2,326	2,645	3,693	4,542
Value £	115,200	127,762	178,543	296,772	497,397	623,074

In addition to the fixed price of 60*s*. per unit, the Government has granted a special allowance of 3*s*. 4*d*. for exchange compensation, and 4*s*. 3*d*. for increased cost of freight.

The chief wolfram field is in the Tavoy district in Tenasserim, while a considerable amount of ore is also produced in Mergui, Thaton and the Southern Shan States. In 1917 the output from Tavoy is estimated at 3,697 tons. At present a considerable proportion of the output comes from residual and alluvial deposits of various kinds, but lode mining is also largely developed [29].

Tavoy is a mountainous district with hills rising up to 6,000 feet, dissected by deep and steep-sided valleys. The rainfall is very heavy, ranging from 180 to 220 inches; hence abundant water power is available, but unfortunately most of the rain falls from April to October only. The country is largely covered by thick jungle, and is therefore difficult of access. Geologically it consists of a series of ancient rocks of unknown age, the Mergui series, mainly composed of quartzites, slates and graphitic schists invaded by biotite-tourmaline granite of late Mesozoic age; the intrusion of the granite was connected with well-marked earth-movements, and gave rise to thermal metamorphism of the sediments. The granite itself contains original wolfram and cassiterite,

while quartz veins are numerous in and near it, striking either N.N.W.–S.S.E., parallel to the general folding, or forming cross-courses trending N.N.E.–S.S.W. Some of these veins, especially the cross-courses, are quite barren, while others are rich in wolfram. They belong to three types, as follows: (1) Wolfram-quartz lodes, which are very common; (2) cassiterite-quartz lodes, (3) wolfram-greisen. So far as is yet known, the two latter types are very rare, though they may eventually be discovered in greater numbers [30]. The distribution of ore in the lodes seems to be patchy, but few of them have yet been opened up for any considerable length, and there is little or no information as to their behaviour in depth, beyond the fact that at greater depths the proportion of tin appears to increase. The other associated minerals are scheelite in small quantity, molybdenite, bismuth, bismuthinite, chalcopyrite, pyrrhotite, mispickel, galena, blende, ilmenite, hæmatite, magnetite, mica, felspar, chlorite and a little fluorspar. Bismuth, molybdenite and sulphides of copper and iron appear to increase in amount downwards [31].

Wolfram and tin disseminated in the granite are important sources of ore: occasionally they occur in sufficient quantity to be worked in place, and much ore passes into alluvium from this type of occurrence. One of the richest float deposits of the district is worked in decomposed granite *in situ*.

Wolfram is now obtained in Tavoy by open-cut workings on the outcrops of lodes, by sluicing on the sides of the hills below the outcrops, by sluicing ground with rich quartz stringers, and by drives on lodes, but underground working is not much developed. In the early days from 1909 onwards most of the ore was obtained by Chinese fossickers working with pans and rough sluices about rich patches on the hill-slopes and in creeks—a very wasteful method. Later work was mostly on the tribute system, but at the present time probably 90 per cent. of the wolfram concentrate is obtained by sluicing shallow detrital deposits, or by hand-crushing quartz from the outcrops of veins. Sluicing operations are greatly facilitated by the dep

covered areas, where the sedimentary rocks are

pletely rotten down to a depth of 300 feet. In more

country, however, the rocks are harder and need treatment by the usual methods of lode-mining [32]. Machinery for lode-mining has now been erected at some of the larger mines, as for example at Hermyingyi (Hermyingyi Wolfram Mining Company, Ltd.), and the Kadwe and Kalonta mines of the Tavoy Concessions group, which are under the same management.

Up to the present, however, as before stated, most of the output of the Tavoy district is obtained from alluvium and various superficial deposits. Most of the lodes occur near the crests of the hills, and the weathered material is washed down by streamlets into the river valleys; hence there is a concentration of ore in the beds of the smaller streams in the steep-sided valleys and on the floors of the main valleys. There are three principal types of alluvial or float deposits. Within the granite country the float consists of large boulders of granite with the weathered and comminuted material from the lodes in the interstices between them. This kind of material is rather difficult to work in consequence of the large size of the blocks, and Chinese miners often lose their lives owing to their careless methods of moving them. In the lower ground is a similar deposit of boulders of quartzite with the lode material between and under them, while on the softer slates and schists the deposit consists of a sticky clay, which is rather difficult to work. Along the smaller streams in the hills the float may be only 2 or 3 feet thick, but in the main valleys it may accumulate to a much greater thickness. Along the hill-streams the wolfram is found in the float in good-sized crystals, occasionally as large as a man's fist, but wolfram does not travel well, and in the lower valleys it is often finely divided, and there is much loss in handling by hydraulic methods. Owing to the narrowness of even the larger alluvial deposits, dredging cannot be successfully employed. As an example of the kind of return obtainable from alluvium, the Kanbauk mine may be quoted, where in 1916 a turnover of 362,000 tons yielded an average of 3·31 lbs. of wolfram concentrate per cubic yard; the output of Kanbauk for 1917 was about 350 tons. The composition of the concentrates obtained varies a good deal; some samples run up to over 70 per cent.

of tungsten trioxide, while others may contain as much as 36 per cent. of cassiterite; hence it is evident that magnetic separation is necessary. The proportion of tin is, as a rule, found to be higher at deeper levels.

At the present time over 100 concessions are producing wolfram ore in the Tavoy district, but more than half of these are very small concerns, some being under Chinese management. Only about a dozen mines or groups of mines have a really large output. The most important is Hermyingyi, belonging to the Hermyingyi Wolfram Mining Co., Ltd., with an output of over 1,000 tons of concentrates per annum. This is probably the largest wolfram mine in the world. Other important producers are Kadwe, Kalonta and others belonging to Tavoy Concessions, Ltd., the Pagaye Mine of the Rangoon Mining Co., the Paungdaw Mines of Steel Bros. & Co., and the mines controlled by the High Speed Steel Alloys Mining Co., and by Messrs. Finlay, Fleming & Co. In spite of the recent very great development of the industry in Tavoy, no new mines of importance appear to have been lately discovered; there are, however, occurrences of some promise in two areas, namely, the Pé region, some 50 miles south of Tavoy, which appears to offer good prospects, and the Zimba Valley, a rather inaccessible region some 40 or 50 miles north of Tavoy. Little development has been done in either of these localities, but the general character appears to be very similar to the rest of the Tavoy district.

The Mawchi Mines are situated some 16 miles west of the river Salween in the Karenni State of Bawlake in the Southern Shan States [33]. The lodes consist of a series of vertical parallel quartz veins in granite, marble, quartzite and slate; they are from 3½ to 5 ft. wide, and contain wolfram, scheelite, cassiterite, mispickel and tourmaline. The wolfram and cassiterite occur in flat masses near the walls of the lodes and in nests and patches throughout. This mine is now partly developed, and it is hoped to produce from 100 to 120 tons of tin-wolfram concentrates per month. A new and possibly important discovery is also reported from a locality near Byingyi Peak on the border between the Yamethin district and the Southern Shan States. Wolfram and molybdenite

are found in a very rich reef, and many concessions have been applied for [34].

A certain amount of wolfram is also obtained from the Thaton district of Lower Burma; in 1917 the output was about 100 tons, but no information is available as to the character or development of the mines.

CENTRAL INDIA.—The tungsten resources of peninsular India appear to be very small. Wolframite has been found at Argagaon in the Nagpur district in parallel quartz stringers in a belt of mica-schist, the whole series being some 60 feet wide. The ore was proved in trenches for a distance of 1,350 feet, and yielded a panned concentrate containing 66 per cent. tungsten trioxide. Wolfram has also been found in the Hazaribagh district in Bengal and near Degana station on the Jodhpur-Bikanir railway, in Marwar, with quartz and biotite in veins of granite. The Indian production from 1912 to 1917 is given in the table on p. 3.

Exports of Wolfram Ore from India (including Burma) [1]

In long tons (2,240 lb.)

		1915–16.	1916–17.	1917–18.
To British countries:				
United Kingdom		2,617	4,490	4,782
Straits Settlements		66	133	—
Federated Malay States		64	—	—
Total British countries		2,747	4,623	4,782
To France		40	—	—
Grand total	tons	2,787	4,623	4,782
	Value	£357,439	£700,314	£724,409

MALAY STATES.—The Malay States and the Straits Settlements form the southern part of the great Burmese-Malayan area of mineralization which also extends into Dutch colonial territory in Banka and Billiton. This is the greatest tin-producing area of the world, and tungsten ores are found in association with the tin, though less

[1] Annual Statement of Seaborne Trade of India. Not separately recorded prior to April 1915.

abundantly than in Burma. According to Dr. W. R. Jones [35], the geological features of the mineral region are essentially as follows: the oldest rocks of the district consist of schists, phyllites, quartzites and slates, together with limestones of Carboniferous or Permo-Carboniferous age. All of these are invaded and metamorphosed by a tin-bearing granite, the exact date of which is uncertain, but probably Mesozoic. Lying on all of these are alluvial deposits containing lignite, peat, tin and tungsten ores. The granite has sent out numerous offshoots, dykes and veins into the older rocks, and has produced in them a high degree of mineralization. All the rocks are very deeply weathered and decomposed.

The output from the Malay States has increased considerably in the last few years, as shown in the following table:

Production of Tungsten Ores in the Federated Malay States

In pikuls (133⅓ lb.)

	1913.	1914	1915.	1916.	1917.
	Pikuls	Pikuls	Pikuls.	Pikuls.	Pikuls.
Wolfram . .	3470·6	3987·6	3,940	5,227	7,078
Scheelite . .	310 0	487·0	961	3,433	5,712
Total. .	3780 6	4384 6	4,901	8,660	12,790
Metric Tons .	228	265	296	523	791

Production of Tungsten Ores in the Federated Malay States, by States

In pikuls (133⅓ lb.)

	1913 *	1914.*	1915.	1916.	1917.
	Pikuls	Pikuls.	Pikuls.	Pikuls	Pikuls.
Perak . .	892	708	978	3,645	6,861
Selangor . .	1,918	3,615	2,663	3,837	4,606
Negri Sembilan .	575	62	1,260	1,132	423
Pahang . .	86	—	—	46	15
Total. .	3,471 †	4,385	4,901	8,660	11,905
Metric Tons .	210	265	296	523	754

* Export figures, not corrected for inter-State trade.
† Not including scheelite, 310 pikuls.

730

Ore from outside sources treated in the Federated Malay States is not included in the above figures

The most complete account of the occurrences of tungsten ores in the Malay States is to be found in a paper by Mr. Scrivenor, from which most of the following information is taken [36]. The chief producing States are Selangor, Negri Sembilan and Perak, in the order given. Hence it appears that the output of tungsten ores is not correlated with the yield of tin, the latter being largest in Perak. Wolfram also occurs in Pahang, Kedah and Trengganu. A large proportion of the ore in all these States is obtained from alluvium, but a considerable amount of lode-mining is also in progress.

Perak.—The best known locality is Bukit Rumpian, south of Tapah, where tin-ore and wolfram occur in small quartz veins in tourmaline granite. Near Gopeng similar veins are also found. At Tronoh wolfram was discovered in 1915 in veins in shales near a granite intrusion, and it has also been found in a pipe of tin-ore in the Ulu of the Petai, near Kampar, also in granite.

Selangor.—The wolfram ores come from Ulu Klang, Ulu Langat and Ulu Kanching, from some tributaries of the Serendah River and from the hills behind Ampang. Most of the output appears to come from Kanching.

Negri Sembilan.—The largest producer of mixed tin and tungsten concentrates is the Titi tin mine, where a good deal is obtained by lode-working, and from alluvial deposits. In 1914 1,600 pikuls (100 tons) of wolfram were obtained from lodes at this mine.

Pahang—Wolfram has been found near Bentong, and 6 miles N E. of Gapoi, also in a greisen in the Kuantan district on the Benta-Kuantan road. The export from this State has been very small indeed, and most of the ore seems to come from alluvium.

Scheelite is known to occur at several localities in the Federated Malay States. Near Pulai scheelite is worked close to a contact of granite and limestone; it is derived from a residual red earth due to weathering, and is mixed with various metamorphic minerals. A quartz lode at Salak North carries scheelite and yellow tourmaline, and scheelite

is also mined in a limestone at the Batu Caves in Selangor and at Kanching.

Kedah.—At Sungei Sintok, near Changloon, in Kedah, wolfram ore is found in large quantities in quartz. This occurrence was only in the stage of prospecting in March 1918, but it appears to be very rich, and an output of 50 tons of concentrate a month was confidently expected [37].

In 1917 the State of Kedah exported 126 tons of concentrates from the Kubang Pasu district, where much prospecting is in progress [38].

Trengganu.—In this State, which, like Kedah, is one of the unfederated Malay States on the north-east side of the peninsula, wolfram was first discovered by Chinese in 1907. The most important deposit is on the slopes of Bukit Runtoh, a mountain about 2,000 feet high lying 25 miles from the coast. The country rocks are quartzite, slate and limestone invaded by granite The rocks are traversed by quartz veins from an inch or two up to 3 feet wide, averaging about 1 foot, and carrying wolfram and iron oxides near the surface. In depth copper and arsenic have also been found. The occurrences of wolfram, though rich, are somewhat patchy [39].

AUSTRALASIA

Workable deposits of tungsten ores are found in all the states of the Commonwealth, and in the South Island of New Zealand, the most important, however, are situated near the east coast of the Australian continent, along the lines of Permo-Carboniferous folding which determine the trend lines of the eastern coastal belt [40]. Deposits of commercial value are scattered along this zone, from the northern part of Queensland to Tasmania in the south, and are almost everywhere found near the contact of granite and sediments referred to the Permo-Carboniferous or some older period. This zone of folding is a highly mineralized area, and contains deposits of many metals, notably tin, copper and gold. The tin, however, though abundant, rarely occurs in any quantity in the same veins or lode systems as the wolfram, as is the case in some other countries; and very few tin-wolfram mines are

known. The metals which most commonly accompany the tungsten are bismuth and molybdenum, which are frequently in sufficient quantity to repay extraction and are sometimes in excess of the wolfram ; scheelite, on the contrary, where it occurs, is generally associated with siliceous gold ores, and sometimes with antimony. The remainder of the Australasian deposits are located in South Australia, the Northern Territory and Western Australia, and also in the Otago district of the South Island of New Zealand.

The Output of the Commonwealth of Australia and of New Zealand for the last five years has been as follows :

In long tons (2,240 lb.)

—	1913.		1914.		1915.		1916		1917.	
	Wolfram.	Scheelite	Wolfram.	Scheelite	Wolfram.	Scheelite.	Wolfram.	Scheelite	Wolfram.	Scheelite
Queensland	449	—	338	—	540	2	434	—	402	9
New South Wales	126	44	139½	57½	50	32½	183½	81	118	127
Victoria	¾	—	—	—	14½	—	—	—	22½	—
Western Australia	—	—	½	—	¼	—	¼	—	—	—
Tasmania	68	—	47	—	94½	—	106½	—	—	—
New Zealand	—	221	—	204	—	194	—	266	—	241

The output of the Northern Territory is not given in tons, but was valued at £12,870 in the year 1915–16, and at £20,269 in 1916–17.

QUEENSLAND.—The chief tungsten deposits of this State are situated in the northern portion, not far from the port of Cairns ; the principal producing localities are Mt. Carbine in the Herberton mineral field, and Wolfram and Bamford in the Chillagoe mineral field. The country rock in these districts is either slate or porphyry of Permo-Carboniferous age invaded and metamorphosed by granite. The tungsten mineral, which is almost all wolfram, with only a little scheelite, probably of secondary origin, is associated with bismuth and molybdenum ores, the latter more particularly at Wolfram. The deposits occur both in the granite and the sediments close to the contacts, in pegmatites, quartz veins and irregular pipes,

Exports of Wolfram Ore from Australia

In long tons (2,240 lb.)

—		1910.	1911.	1912.	1913.	1914–15.	1915–16	1916–17
To British countries								
United Kingdom		306	205	152	123	251	911	983
Belgium		2	11	77	5	—	—	—
France		196	120	120	92	164	21	—
Germany		610	816	660	536	70	—	—
Other countries		—	—	12	—	—	—	—
Total tons		1,114	1,152	1,021	756	485	932	983
	£	116,440	119,569	97,647	80,790	48,693	165,139	181,048
From								
New South Wales		835	859	826	640	403	882	983
Victoria		56	38	40	42	21	5	—
Queensland		164	191	115	55	50	45	—
Northern Territory		—	54	40	19	11	—	—
South Australia		57	1	—	—	—	—	—
Western Australia		2	9	—	—	—	—	—

Exports of Scheelite from Australia

In long tons (2,240 lb)

		1910.	1911.	1912.	1913.	1914–15.	1915–16	1916–17
To British countries:								
United Kingdom		1	3	29	3	2	54	85
Belgium		—	—	—	6	—	—	—
France		83	18	7	15	29	—	—
Germany		67	106	20	23	—	—	—
Total tons		151	127	56	44	31	154	85
	£	15,777	13,112	4,963	4,459	3,089	9,853	15,883
From								
New South Wales		151	127	56	44	31	54	85

often accompanied by silicification and greisenisation of the country rock.

Mt. Carbine [41]. Here the ore is found in pegmatite veins which are confined to a somewhat restricted portion of the slate-granite contact, the mineralised area measuring 1½ by 1¼ miles. The deposits are tabular in form, and are arranged in about twelve radiating zones. The strike of the veins is slightly oblique to that of the slate country, and, where these lines cross, bands of richer and poorer ore are found. The veins are clean cut and do not alter the rocks through which they pass to any extent; no greisenisation has taken place, and the granite is only rendered slightly micaceous, while the slates are somewhat silicified. The lodes have a tendency to peter out, but, since a new vein is almost always found overlapping the old one, the drives can be carried straight along the same general direction. The gangue generally takes the form of a quartz felspar rock, with predominant quartz, the wolfram being richer where the felspar is in greater amount. The only metallic mineral of importance is wolfram with a little secondary scheelite. Some molybdenite and cassiterite are also found, but in very small quantity.

The early mining in this locality was confined to the digging of the rich shoads or residual surface deposits. Only the richest ore was removed in this way, but good values are now being obtained by passing the old dumps through the mill. As these deposits became worked out, lode mining was begun by single miners and small syndicates, but, as the mines became deeper, and the richer deposits were worked out, this form of mining became unprofitable, and most of the claims came into the hands of the Irvinebank Company, who erected a mill and exploited the ore in a systematic manner. It is reported, however, that they are now worked by the Thermo-Electric Reduction Company, of Luton, Bedfordshire, who have recently bought the property [42]. The veins vary in width from a few inches up to 6 feet, the average now worked being about 2 feet wide. The method of development employed is to drive along every ore body of 20 inches wide and upwards, and the stone thus obtained has an average content of 1¾ per

cent. WO_3. In 1912 the company had 25,000 tons of ore in veins of 18 inches wide and upwards on one claim, Mt. Carbine No. 1; the reserves of the fields must be many times greater than this, and it is still the most important producer in Queensland.

Wolfram [43]. This town, till recently called Wolfram Camp, was the first tungsten field to be developed in the State, and now stands second in production after Mt. Carbine. The country rocks here are granite and quartz porphyry, with a considerable amount of greisen. The ore occurs both in contraction fissures in the granite, and in a series of irregular pipes in the greisen, which are probably formed along the intersection of two joints. The fissures are mostly horizontal, and extend for a short distance from the veins which connect them; these carry tungsten values themselves and serve to lead the miner down to lower horizontal ore bodies. The horizontal fissures, though rich, are never more than 10 to 12 inches wide, but the vertical veins sometimes open out to a width of from 3 to 4 feet, though only for a few yards at a time. The gangue in most cases is clear quartz. The metallic minerals are wolfram with bismuth and molybdenite, the last being in sufficient quantities to form a payable ore. Up to 1916 the most important lodes were worked by the Murphy and Geary syndicate, but, in that year, this mine and several of the others in the district were acquired by the Thermo-Electric Reduction Corporation, of Luton, Bedfordshire [44], who intended to transport to the field the entire plant of the Trenwith Mine in Cornwall, and hoped to raise the output to 1,000 tons of 60 per cent. concentrates annually. The company has for the first time introduced mechanical drills and other machinery to the field, and is following a systematic development of the low- as well as of the high-grade ore, which alone has been mined up to the present [44].

Bamford [45], in the Chillagoe mineral field, is two miles north of Petford station, on the Chillagoe railway. The country rock is granite intruded into quartz porphyry. The ore deposits are found in the granite alone, along a small portion of the contact, associated with greisen and quartz rock, in irregular pipes like those of Wolfram; these pipes

occur along the main joints which dip in a direction nearly parallel to the granite-quartz-porphyry contact. They are filled with quartz carrying wolfram and molybdenite, which together rarely exceed 1 per cent. of the ore. Scheelite is fairly common as a secondary mineral after wolfram.

In the pipes are many vugs, which are sometimes as much as 20 feet long, and contain, in addition to wolfram and molybdenite, bismuth and some copper and lead. There is a complete absence of cassiterite from the productive area. Up to 1916 the ore was all dressed by hand, but in that year a State battery and concentrating plant was erected on the field. In addition to these three districts, which provide almost the entire output of the State, tungsten ores are found at a great number of other places.

In the southern part of the Herberton mineral field small returns are reported from Gurrumba, Butcher's Creek and Upper Nettles Creek near Coolgarra, Stannary Hills and Emuford; at the last two places the mineral occurs with tin, molybdenum and bismuth, in veins associated with greisen in granite, and at the latter, where rich ore has lately been discovered, monazite and fluorspar also are found Mining has also been carried on at Mt. Molloy and McLeod's River in the northern part of the field near Mt. Carbine, and in the Tinaroo district.

In the Chillagoe field occurrences are reported from Eight Mile Camp, Upper Lynd River, Mt. Surprise, Truxillo and Fossilbrook, at the last of which 24 tons of concentrates were obtained in 1916.

Deposits are also known on the Pascoe River in the northern part of the York Peninsula and on Noble Island, at China Camp and Hartley's Wolfram Lode in the Cooktown District tin-field, the Perseverance Mine above Kidston and Buchanan Creek in the Etheridge mineral field, Kangaroo Hills near Halifax, Ollera Creek, 50 miles north of Townsville, Ravenswood near Wangaratta, the Rosedale district near Bundaberg, and the Stanthorpe district near the Sugarloaf Mountain on the New South Wales border. In the Stanthorpe field, which is really part of the Wilson's Downfall tin and wolfram field of New South Wales, wolfram is found with tinstone in

micaceous quartz veins, in a fine-grained acid granite and its apophyses, along a granite-slate contact. It is associated with tin, silver, molybdenite and mispickel, and occurs also in places disseminated through the granite.

The production of Queensland for 1915, 1916 and 1917, in long tons (2,240 lbs.), has been as follows:

—	1915.		1916.		1917.	
	Wolfram.	Bismuth wolfram	Wolfram.	Bismuth wolfram.	Wolfram.	Bismuth wolfram.
Chillagoe . .	196¼	237½	110¾	126	125	122
Herberton . .	198	9	227	8	201	8
Other districts .	21¾	½	32¼	2½	26¾	1½
Total . .	416	247	370	136½	352¾	131½

New South Wales.—Tungsten minerals are reported to occur in many different places in this State, but the deposits of any great economic value are all situated in the north-eastern portion, not very far from the Queensland border, and near Broken Hill in the west. Both wolfram and scheelite are represented, the former being worked chiefly on the Mole Tableland, near Broken Hill, at Hogue's Creek, and in the Frogmore district in the Hill Grove area [46].

The Mole Tableland, near Torrington, is the most important wolfram mining district, three companies being established there. The tableland, which is about 4 miles square, is mainly composed of granite, which was intruded into slates and claystones, small patches of which have escaped denudation, and the ore deposits are found at or near the contacts. The ore occurs in three different ways, in a quartz-topaz rock, in fissure veins and altered pegmatites in the slates, and as lodes along the centre of greisenised zones in the granite. The quartz-topaz rock contains a little felspar and takes the form of both dykes and sills; it carries wolfram and bismuthinite, with the former largely in excess. The wolfram occurs mainly scattered through the rock, but also in bunches and along joint faces, so that, though the whole mass is not

payable, tributers make good profits by following the rich ore. The bunches which are often associated with vugs are sometimes very large, one lump of 12½ tons of clean wolfram having been discovered in a vug in the New Hope Mine at Torrington. Where the rock occurs in the form of dykes it is worked by shafts, as at the Torrington Ore Company's bismuth mine, in which the workings have been extended to a depth of 300 feet with no falling off in the quality of the ore; but at other places, where it takes the form of an undulatory sill, as on the Rockvale Wolfram Mines property, it is worked in open quarries.

Between Yanco Glen and Thompson's Siding, about 20 miles from Broken Hill [47], several parallel wolfram-bearing lodes have lately been proved over a distance of between 9 and 11 miles, and are now being actively worked. The ore bodies are fissure veins traversing micaceous schist and quartzite country; their strike is nearly north and south, and they are somewhat faulted. The wolfram content of the ore varies from 2 to 6 per cent., and in addition some very rich "slugs" are found. A number of syndicates and claim-holders are engaged on the field, and on one lease alone at Thompson's Siding, it is estimated that there is £7,000 worth of ore in sight. The field is well situated with regard to water, and promises to be capable of a considerable output, when concentrating machinery has been installed.

The other types of occurrence are not of much economic importance. The fissure veins may be divided into true quartz veins with wolfram in patches, and altered pegmatites, where the ore is distributed through the rock.

Apart from the Mole Tableland and Broken Hill deposits, the only important field is the Frogmore district, which in 1916 produced 22 tons of concentrates.

Small outputs are recorded from the Edith Mining Company's mine at Cow's Flat on the Mole Tableland, the Glen Innes Mine at Hogues Creek, the Pulltop district near Wagga Wagga, Yalgogin, Emmaville, Deepwater, Burrowa, Ardlethan and Wilson's Downfall, and Tenterfield near the Sugarloaf Mountain on the Queensland Border. The last two places are in the same mining field as Stanthorpe in Queensland,

and the occurrence of the ore is the same [48]. Deposits are also being prospected on Yanco Glen, near Broken Hill [8].

The Hillgrove Scheelite Deposits.—These are found in lenticular patches along the contact of a gneissic granite and a spotted slate, and also as well-defined lodes associated with siliceous gold-reefs in the granite and slates. The scheelite veins are generally found on either side of the gold-reefs and parallel to them, though in some the gold ore gives place to scheelite in patches. They are from 1½ to 6 inches wide, and are richest where they are cut by cross courses or faulted, some of them occupying the fissure veins, while others fill contraction cracks in the granite. The ore is patchy and the values tend to increase downwards, as do those of the gold ores. The values have been proved to persist to a depth of over 1,500 feet in deposits on the sides of Baker's Creek Gorge, and have been followed to 200 feet in the Baker's Creek and Proprietary Mines. The gangue is chiefly quartz, and the scheelite is often associated with stibnite. The mineralised area is 4 miles long by 2 miles broad, and contains several mines, including the Bullfrog, Hopetown and Damifino Mines, the last being by far the largest producer.

Scheelite is also recorded from a number of other localities, among which are Beck's Point, Nundle and Metz, which produced 5 tons 16 cwts. in 1916.

In addition to wolfram and scheelite, stolzite is reported from a lode in the Broken Hill district, but this occurrence is of no economic importance.

VICTORIA.—The output from this State has always been very small, and no deposits of great economic value exist.

The two areas which have made any production worth recording are Mt. Murphy, near Benambra [49], where wolfram occurs in a quartz vein in schist and granite country, and Lintons, near Baragwanatti [50], where many quartz veins cut metamorphic slates which are invaded by granite; two of these contain wolfram together with specks of gold. The lodes strike E. of N., and are 9 inches and 10 feet wide respectively. The ore is found in stringers in the lode formation, and yields about 2·5 per cent. of tungstic acid, and from 1 to 7 dwts. of gold per ton.

4

Wolfram and scheelite occur at Maldon [51] on the Buckwong River, and at other places in the State, including Koetong [52] in the Beedworth district, where scheelite is found with cassiterite.

TASMANIA.—Wolfram is found associated with tin, molybdenite and bismuthinite at several places in the northern part of the island, the chief localities being Constable's Creek and Upper Scamander, Gipp's Creek, Storey's Creek and Moina [53]. The country rocks in all cases are sediments, either quartzites and slates or quartzites and limestones, as at Moina, invaded by granites of Devonian age. The deposits take the form of quartz veins and greisenised bands, pegmatite and quartz-porphyry dykes, and irregular pipes like those of Bamford in Queensland. The wolfram is always patchy, and, where it is found with cassiterite, the two are never intergrown, but occur in separate aggregates; the metallic minerals are associated with fluorite and topaz in the gangue. The chief producers are Gipp's Creek and Storey's Creek, which in 1916 produced 7 tons of concentrates per month, and Moina, which in the same year was producing about 6 tons per month.

At Gipp's Creek there are three parallel lodes striking a little west of north and carrying both tin and wolfram; the ratio of tin to wolfram decreases from the north, where tin is the predominant mineral, to the south, where the lodes carry mainly wolfram. Their average width is 1 foot, they persist over a distance of about 1 mile and are being worked along the whole length.

At Story's Creek there are two main lodes, one striking N. 25° W., the other N. 10° W., and dipping to the west from 37° to horizontal, and their average width varies from 3 to 4 feet. The lodes, which carry wolfram and cassiterite in separate aggregates, are now being worked by a syndicate with good results. The wolfram at these two places is so coarsely crystalline that crushing by stamps should be avoided, as the ore can be obtained at a sufficient concentration with minimum loss, by coarse crushing with jaw-crushers and rollers. At Moina a number of mines are in operation, the most impor-

tant of which are the Shepherd and Murphy and the All Nations Mines. There are several lodes, and the veins vary in width from 3 to 20 inches. The metals produced are tin, tungsten and bismuth, with a little molybdenite.

In addition to these wolfram deposits, there are considerable amounts of scheelite on King Island, in the Bass Strait [53] The ore deposits occur near the mouth of the Grass River, on the south-east coast of the island, at a short distance from the margin of a granite mass, intruded into slates and sandstones. The ore-bearing rock, which seems to represent an altered limestone, consists chiefly of garnet, and covers an area of 65 by 85 feet, as far as it has been proved at present. The scheelite is disseminated through the mass, but also occurs in rich masses in quartz veins traversing the ore rock. The average value of the ore is 1·69 per cent. WO_3, and the mining and separation appear to offer no difficulties. The garnet rock is associated with an aplite dyke carrying scheelite that probably indicates the channel up which the metalliferous solutions rose. There are also other deposits of scheelite-bearing garnet rock on the island, but these have not yet been opened up.

South Australia.—In this State tungsten ores have only been mined at one place, Callawonga Creek, near Normanville [54]. The ore here is very pure ferberite containing only 0·17 per cent. of MnO, and is found in pegmatite veins in a crystalline micaceous sandstone. The veins are mostly vertical and strike N.W.–S E. The gangue minerals are quartz, mica, felspar and pyrites. The felspar is largely kaolinised, which is regarded as a favourable sign, since the ore, which tends to occur in pockets and shoots transverse to the vein, is often associated with this mineral. The veins are from a few inches to 2 feet wide, and sometimes occur close together, so that the lode formation reaches a width of 6 feet. They have been worked to a depth of 36 feet. The output has so far been small, but the prospects are said to be promising.

Northern Territory.—In this region deposits of tungsten ores have been worked at three localities. Two of these, the Pine Creek district and Brock's Wolfram Mine, are situated in

the north-western part of the territory, and the third, Hatches Creek, in the centre, about 50 miles south of Lake Sylvestre. In the north-west the deposits are distributed along the south margin of the Pine Creek massif [55], at Yenberrie, Wolfram Camp and several other places, the most important of which is Yenberrie, about 35 miles by road from Pine Creek on the Port Darwin–Pine Creek Railway. The country rocks are pre-Cambrian tuffs invaded by granite. The ores are wolfram and molybdenite, and occur in quartz veins and aplite dykes, which also carry mispickel, a little bismuth, and low copper values. The richest deposits are in the quartz veins, where the metallic minerals form large crystals and are easy to separate. These alone had been worked by the claim-holders in 1916, and then only to water-level, about 30 to 40 feet. During the year 1916–17 30 cwts. of concentrates were produced per month by one of the two chief mines. The other locality in this region is Brock's Wolfram Mine [56], about 7 miles south-east of Wandi, where a lenticular pipe containing massive wolfram associated with scheelite and copper pyrites in quartz cuts through indurated argillaceous sandstone and slate. This deposit showed no diminution in size at a depth of 30 feet. The ore is also found in small veins in this locality, and in diorite and a metamorphosed sandstone near Irwin's Copper Show.

At Hatches Creek wolfram is found in quartz veins traversing dioritic rocks [57]. The veins are from 1 inch to 4 feet thick and carry, in addition to muscovite, iron and bismuth oxides, copper carbonates and molybdenite. The lodes are numerous and well defined, and show considerable persistency along the line of outcrop. The development, however, is impeded for lack of capital and transport facilities, but 35 tons of concentrates were produced in the year 1916–17 [58]. A small amount of wolfram is also mined at Wanchope's Creek, 80 miles west of Hatches Creek.

Western Australia.—Wolfram and scheelite are found in a number of localities, though usually in small and irregular deposits, associated with gold ores. At several of these places the minerals could be saved by concentrating tables, but, up to now, they have been allowed to run to waste. Scheelite

is the more common, occurring in many of the goldfields, associated with siliceous gold ores, and has been exported from the Yalgoo and Murchison fields. Wolfram has a smaller distribution, but has been reported, among other places, from Coolgardie, Kalgoorlie and Poona in the Murchison goldfield [59]. The output has been somewhat variable, but always very small.

New Zealand.—Scheelite occurs in a large number of the quartz veins of the Otago goldfields in the southern portion of the South Island [60]. It has, however, only been found in workable quantities in two districts, Glenorchy and Macrae's Flat; and of the various workings only three mines survived beyond the early stages of development. These are the Glenorchy Mine at Glenorchy, and the Golden Point and Highlay Mines at Macrae's Flat.

The country rock throughout is quartzose mica-schist, graduating into phyllite and slate. The veins are of two types, fissure veins at Glenorchy and elsewhere, and bedded or segregated veins at Macrae's Flat. They are also divided into two types economically, those which are worked mainly for their scheelite content, with gold as a by-product, and are treated by coarse crushing, as at the Glenorchy mine and Golden Point, and those worked chiefly for their gold content, with scheelite as a by-product, as at the Highlay Mine.

The Macrae's Flat district, about 40 miles north of Dunedin, is situated on a plateau about 2,000 feet above the sea. The mineralised belt is from ½ to 2 miles wide, and runs more or less continuously for a distance of 16 miles from Stoneburn to the Highlay Mine. It is highly mineralised with occasional cross-belts, carries isolated shoots of ore, and is seen in places outcropping for a distance of 3 miles.

At Golden Point, about a mile north of Macrae's Township, there are three lodes striking N. 40° W., and dipping 10° to 25° N.E. These are 15 and 25 feet apart respectively. The middle lode is from 3 to 6 feet wide, and carries from ½ to 1 oz. of gold to the ton, as well as a high content of scheelite, which is disseminated through the gangue, and also found in pockets of nearly pure ore. The top lode is 3 to 4 feet wide, with rather low values, and the third is of little importance. The

gangue is quartz, and carries, besides scheelite and gold, pyrites, arsenic, sulphur and rhodonite. The lodes are much faulted and hard to follow. The pockets of rich ore are always near the walls, more often the foot-wall. The firsts are concentrated by hand to a content of 60 to 65 per cent. WO_3, and the rest of the ore is milled and treated for gold and scheelite.

At the Highlay Mine, about 5 miles away to the north-east, there are two lodes striking N. 30° W., only one of which gave any constant output. This mine was closed in 1913.

The Glenorchy Mine is situated on Mt. Juda, near Lake Wakatipu, about 240 miles N.W. of Dunedin; the lode strikes S.E.; it is from 1 to 8 feet thick, and outcrops for nearly a mile along the strike. The gangue is dense quartz with gold, scheelite, pyrites and mispickel. The scheelite is distributed through the gangue in lenticular masses from an inch to 2 feet in thickness. These masses cut in and out in a very irregular manner and all carry high scheelite values.

Numerous other deposits of scheelite, all unpayable, are found in the Otago district, covering country stretching from Lake Wakatipu to near Palmerston, and, in addition, wolfram is reported from Stewart Island and the western parts of Nelson, but in neither case is it worth mining.

AFRICA

Union of South Africa

Tungsten minerals are reported to occur in various parts of the Union of South Africa, but up to the present no deposit of importance has been found. Wolframite occurs associated with cassiterite at Kuils River in the Cape Province, and also in some parts of the Waterberg tin-fields in the Transvaal. Scheelite has been found in some quantity in the Transvaal at the Stavoren Tin Mine, and also near Leydsdorp.

The output of tungsten in the Union of South Africa is reported as 1·432 and 8·615 short tons for 1916 and 1917 respectively. This output was from the Transvaal, with the exception of 2·164 tons from the Cape in 1917.

In connection with the deposits of the Union of South Africa, mention should be made of those of South-West Africa, where tungsten minerals occur at various localities. Wolfram has been found in pegmatite veins traversing granite 10 or 12 miles S.E. of Little Karas, and 2 miles from the railway line running from Seeheim to Kalkfontein in Great Namaqualand, associated with chalcopyrite and molybdenite. The surface gravels of the district also contain wolfram. Wolfram is found as radiating masses in granite at Ubib and Goages in the Swakopmund district. It is also reported to occur in the pegmatites of the Erongo Mountain area [61].

RHODESIA

According to a report recently issued by the Director of the Geological Survey [62], wolfram and scheelite occur at numerous localities in Southern Rhodesia: from Wankie to Umtali, and from Lomagundi to the Limpopo River. Three types of occurrence can be recognised, as follow: (*a*) acid dykes, varying from aplite to pegmatite, often more or less converted into greisen—these are found both in the marginal parts of granite masses and in the schists surrounding them; (*b*) gold-quartz veins with sulphides and disseminated scheelite; (*c*) an association of tungsten ore with copper ores in quartz reefs.

In this region scheelite seems to be, on the whole, more abundant than wolfram; it is found in small quantities in the Wankie district, and in association with bismuth minerals 40 miles east of Lusaakas, in Northern Rhodesia. In the Umtali district scheelite has been found with tinstone and tantalite in the Odzi reserve, and in a garnet-actinolite rock near Old Umtali. It is said to be common in small quantities in reefs near Bulawayo, and near Que Que in the Gwelo district it is reported in a quartz reef with gold. The gold-quartz reefs on the Mombi River also contain some scheelite, and a copper-bearing variety comes from Sinoia, in the Lomagundi district. In the Gwanda district wolfram is reported from places in the country south and west of the Umzingwane coalfield. The Scheelite King Mine, 9 miles west of Gatooma,

in the Hartley district, produced a few years ago 40 or 50 tons of ore from a quartz reef near the margin of a granite mass. Tungsten ores also occur in dykes and reefs near the margins of granite near Selukwe, and in the Ndanga district near the Sabi River in a country rock of chlorite schist.

By far the most important tungsten occurrence in Rhodesia is that at Essexvale in the Umzingwane district, which has been made the subject of a special report by Mr. A. E. V. Zealley [63]. Here sixteen distinct reefs are known, striking E.–W. and dipping N. at from 30° to 50° They consist of greisen formed from aplite, porphyry or pegmatite, with lenses of quartz and very finely disseminated wolfram and scheelite, as well as fluorspar, tourmaline, topaz, and a little galena. In April 1917 prospecting was in active progress, and concentrates were obtained containing up to 74 per cent. tungsten trioxide. In this area also patches of so-called "rubble," a residual deposit, lying on and near the reefs, yielded from 2 to 8 lb. of wolfram per ton. The scheelite was at first thrown away, but now adds much to the value of the concentrate. Here the best results have been obtained with the ordinary rotary diamond washer, while in some places simple hand-picking by natives has yielded considerable amounts of ore; near the western end of the Lunar Block Reef 1,600 lbs. of wolfram were obtained in this way.

The production of wolframite in Rhodesia during 1916 and 1917 is reported to have been about 2½ and 11¾ short tons respectively. The total production of tungsten ore up to the end of 1917 was 142½ short tons.

AMERICA

CANADA

Tungsten ores are found in several very widely separated districts in the Dominion, in the provinces of Nova Scotia, New Brunswick, Manitoba and British Columbia. Of these, the first two are the most important, though the output of the whole Dominion is very small.

In Nova Scotia [64] scheelite occurs on Stillwater Brook,

near the Moose River gold mines in Halifax county, in quartz veins interbedded with folded quartzites and slates over a zone 100 yards in width. The scheelite is concentrated at the apices of the anticlines and synclines, so that the ore bodies take the form of lenses, which contain, in addition to quartz and scheelite, mispickel, white mica, felspar, tourmaline and brown calcite. The average width of the veins is 2 inches, though they are sometimes 22 inches wide, and have a normal value of between 0·22 and 0·25 per cent. WO_3. The mine has a possible reserve of 85 tons of 72 per cent. concentrates.

In New Brunswick, at Burnt Hill Brook [65], a tributary of the Miramichi River in York county, wolfram is found associated with molybdenite, pyrrhotite, cassiterite, pyrites, mispickel, mica, topaz and fluorite in quartz veins traversing argillites, about three-quarters of a mile from a granite intrusion. The stronger veins strike N. 25° W. at right angles to the direction of the argillites, and are crossed by weaker veins parallel to the strike of the country rocks, the mineralisation being increased where the two intersect. The only important vein is from 1 to 2½ feet wide, swelling in places to 9 feet. It strikes N. 40° W. and is exposed for a distance of 150 feet, though it probably extends at least 650 feet further under drift. The wolfram is irregularly distributed, and occurs as large crystals both in the vein and in the wall rock. The vein pinches, swells and splits, but its character is found to remain uniform to a depth of 50 feet. The ore contains on the average about 2½ per cent. WO_3. The mine was closed in 1916, but has since been restarted.

In Manitoba scheelite associated with molybdenite has been found in a series of pegmatite dykes, associated with granites, which invade very old schists in the Falcon Lake district. A small production was expected in the autumn of 1918.

In British Columbia there is wolfram in important amount in one of the veins of the Black Prince Group, lying south of the Bulkley River in the Hazleton district. The ore occurs in distinct shoots in veins of fissure-replacement or shear-zone-replacement types in Pre-Cambrian rocks which are invaded by later granites. Scheelite has for some time been known to occur at Hardscrabble Creek [64], in the Caribou

district near Barkerville, in auriferous quartz veins and impregnation zones in mica schist, one of which is from 3 to 8 feet wide. The ore is of good value, but, owing to the remoteness of the district, none has yet been exported.

Wolfram with scheelite and a considerable amount of tungstic ochre is found in gold-bearing quartz veins traversing Palæozoic rocks, granite and associated igneous rocks in the Kootenay district [64]. Neither the tungsten nor gold values are very high, and would only pay if worked together.

No output is yet recorded from British Columbia.

A little scheelite is reported to occur in the gold-bearing placers of Dublin Gulch, near Mayo, Yukon Territory, which have their origin in an impregnated granite [66]. About 10 to 20 tons of concentrates were expected to be ready for shipment in 1917.

CHAPTER III

SOURCES OF SUPPLY OF TUNGSTEN ORES—(*continued*)

(*b*) FOREIGN COUNTRIES

THE outputs of tungsten ores in foreign countries are shown in the world's production table on p. 3. As will be seen from that table and the accompanying diagrams, the chief foreign producer is the United States. Next in importance come South American countries as a whole (including Bolivia, Peru and Argentina), Spain and Portugal, and Siam.

EUROPE

SPAIN AND PORTUGAL

The tungsten ores of Spain and Portugal are found, generally in association with tin, in a broad belt of country beginning in the north-west of Galicia, in the provinces of Coruña, Pontevedra and Orense, and extending through the northern half of Portugal and the Spanish provinces of Zamora, Salamanca, Caceres and Badajos; on the south this region is cut off abruptly by the great Guadalquivir fault. In general terms the mineralised zone consists of Archæan gneisses and schists enclosing synclines of Palæozoic sediments, the whole being invaded by great masses of granite [67]. The ore-deposits are mostly localised at and near the granite contacts. There are also other scattered occurrences in the provinces of Córdoba, Jaen and Málaga [68].

It is difficult to obtain reliable and up-to-date information as to the details of Spanish and Portuguese mining areas. Much confusion has been caused by vagueness of geographical description in the literature, and by the fact that the same occurrences have been frequently described under different names. It is still uncertain how much of the present output is derived from alluvial deposits and how much from outcrops of

lodes worked in a small way by the peasants. However, lode-mining is now in operation on a considerable scale in several districts, under the control of foreign capital. The outputs for Spain and Portugal during recent years are shown on p. 3.

Spain.—In the province of Coruña the San Finx mines, near Lousame and Cabana, were worked many years ago by an English company on a considerable scale. Veins in schist and granite, up to 30 inches wide, contain both cassiterite and wolfram, and the output is stated at one time to have reached 680 tons per annum. The Tyre and Sidon Mine at Carbia, in Pontevedra, was also a considerable producer, and another important mine is near the village of Silleda [69].

The production from the province of Zamora is now very small, amounting to only a few tons yearly; this region seems to be nearly worked out. A few tons of ore have recently been obtained from shallow workings near the village of Barruecotardo in Salamanca. Although very remote, this locality seems to be promising. The province of Caceres also yields a few tons from veins of the usual type.

At present most of the Spanish output comes from Badajos. The best-known occurrence is in the district of Oliva de Jerez and Zahinos, near Jerez de los Caballeros [70]. The most important mine is La Virgen de la Gracia. Here the country rock consists of red or grey gneiss with much tourmaline, and pale mica-schists, all penetrated by masses of granite and diorite. Ten lodes are known up to 30 inches wide, with walls of greisen and a filling of quartz, oxidized iron and manganese ores with traces of gold. The average yield is 5 to 7 lbs. of wolfram per cubic yard of lode-stuff; in one place a large-scale test yielded 90 lbs. of 70 per cent. concentrates per cubic yard, while some of the thinner parts of the lodes are plates of almost pure wolfram. There is also a large deposit of alluvium, 30,000 cubic yards of which yielded an average of 12 lbs. of wolfram per cubic yard, mostly in small lumps. Occasionally very large lumps are found, and one weighing 550 lbs. is recorded.

The Tres Amigos Mine, near the village of Valle de la Serrana, is worked by a French company at Orleans. The country consists of Ordovician slates and quartzites penetrated by

small granite stocks. The ore occurs in quartz veins and also as impregnations in the quartzites. Eight lodes from 10 to 12 inches wide have been followed for about two miles, and are worked in open cuts. The ore is very irregularly distributed, and only the rich shoots have been worked.

Wolfram has also been recorded from various localities in the provinces of Córdoba and Jaen. At the La Sorpresa Mine in Córdoba wolfram and scheelite occur in quartz veins at the contact of Cambrian slate and granite. These are worked by open cuts, and after hand sorting are crushed and concentrated. The concentrates obtained are of high grade, containing up to 74 per cent. of tungsten trioxide from wolfram, and 80 per cent. from scheelite ore. Near the great lead region of Córdoba, at the village of Conquista (Peñarroya), three wolfram lodes with an average width of nearly 4 feet show good prospects. In 1916 exploitation was only just beginning, but the output was about 60 tons [71]. In the same year a French company began to explore a promising occurrence near Málaga, and it is stated that in 1915 Almeria produced 2 tons. There is a large number of small mines in the Paterna district of that province.

Portugal.—Wolfram ores occur over a very considerable area in the northern half of Portugal, and at the present time this country is by far the largest producer in Europe [72]. In the northern province of Tras os Montes the most important mine is at Borralha, in the Serra das Alturas, 15 miles S.W. of the town of Montalegre; this is extensively worked by a French company. The ores chiefly occur at and near the contact of granite and crystalline schists; the veins strike N.E.–S.W., and dip to the N.W. The ore is free from tin, sulphur and phosphorus, and in 1917, 550 tons of 65 per cent. concentrates were shipped by road and rail to Oporto. The mine is worked by hydro-electric power, and employs about 500 men and women. Wolfram is also mined at Bentosellos in the Cerva district. At the Montado de Adoria Mine, about 20 miles due south of Montalegre, fifteen or sixteen large veins and a stockwork occur in granite. In spite of very primitive methods, almost entirely hand work, the output in 1917 was about 200 tons.

In the eastern part of Tras os Montes, near Bragança, are several mines of some importance. In this region the rocks seen at the surface consist chiefly of crystalline schists, but granite occurs at no great depth. At Iffanes, wolfram occurs in a lode at the contact of schist and porphyry in association with iron pyrites. Although the mine possesses a very elaborate plant, so far only the oxidised zone has been worked. Other mines are at Parada, Paradinha, Valle de Seixo and Coelhoso; at the last place wolfram is associated with sulphidic copper ores and autunite (uranium calcium phosphate). At Mirandella and at Miranda do Douro, on the Spanish border, wolfram occurs at the contact of granite and schist: most of these mines also yield tin-ore. South of the Douro, wolfram is found over a large area, the most important district being that on both sides of the Serra da Estrella. The Serra de las Mesas, a projection on the south-east side of this range, is one of the most highly mineralised regions in the Iberian peninsula.

The most important mine of this region is the Panasqueira at Silvares, near Covilhão, in Beira Baixa; this is worked by the Wolfram Mining and Smelting Company, an English concern, and the output has recently been about 30 tons of concentrates per month. Here wolfram occurs in quartz veins in slates and greywackes, said to be of Cambrian age. The lodes are several miles away from any visible outcrop of granite, a somewhat unusual feature. The associated minerals are cassiterite, mispickel, iron pyrites, specular iron-ore and mica; hence a somewhat elaborate system of concentration is necessary. Wolfram is also found over a considerable belt of country in the neighbourhood of Fundão and Sabugal; it occurs chiefly near the granite contacts, but there is also a good deal of alluvium, while peasants working along the outcrops produce an appreciable amount of ore. At Matta da Reinha, 7 miles from Prazeres station, a stockwork of wolfram ore occurs in a granite boss; the mass is some 250 feet long by 100 feet wide. There are also lodes passing into Cambrian slates. Six thousand tons of vein-stuff from open workings yielded 140 tons of ore with 5 per cent. of wolfram. Solid masses of ore have been found up to 1 ton

in weight. The ore contains very little arsenic and no tin, hence it is of very good quality. At Pinhel ore is also found along a contact of granite and slate. At São Cosmado, a few miles from the city of Vizeu, 15 tons of concentrates were obtained in 1917. At Moimenta da Beira, 20 miles S.W. of São João de Pesqueira, the output for 1917 was 250 tons, thus making this mine one of the largest producers in Portugal; while a mine at Paredes in the same neighbourhood produced 125 tons. In the Arouca district south of Oporto a good deal of prospecting has been done; the Capela do Senhor dos Aflitos is said to be promising, though no details are published.

In Portugal the wolfram deposits are generally irregular, and often have a lenticular form with a maximum width of some 3 feet. The continuous lodes also rarely show a greater width than 3 feet, although occasional bulges are found up to 10 or 12 feet, or even more. The vein-stuff is usually white or yellowish quartz with mica, and the only other mineral of any importance is mispickel, although iron and copper pyrites and galena are also recorded. Some rich wolfram deposits are found in horizontal cracks in the granite, forming "flat lodes." Most of the wolfram veins contain little or no tin, while the tin veins contain no wolfram. In one case a number of small wolfram and tin veins are associated, almost forming a stockwork, yet the wolfram veins contain no appreciable tin and vice versa. There are, however, in the north of Portugal, some big lodes carrying both minerals in about equal proportions.

Besides the lode-mining as above described, wolfram and tin are also obtained from alluvium in Portugal by dredging and similar methods. Near Vizeu several mines, such as Dias, Ramelho Vieira and Pendão, turn out a large quantity of concentrates from alluvium as well as from fissure veins in granite. The tin- and tungsten-bearing area in the Guia valley, on the eastern side of the Serra da Estrella, is about 3 miles long and several hundred yards wide. In this area dredges are worked by electric power [73].

The following table shows the exports, in metric tons, of tungsten ores from Portugal to different countries for the years 1911–14 inclusive:

To:	1911.	1912.	1913.	1914.
Germany	458	365	581	269
Belgium	50	10	36	8
United States	40	20	—	40
France	628	751	605	454
Holland	10	3	3	1
England	26	82	129	153
Total	1,212	1,231	1,354	925

France

Tungsten ores are found in Brittany under conditions showing much resemblance to those of Cornwall, but in much smaller quantity. The most important occurrence is at Montbelleux, in the Department of Ille-et-Vilaine, where quartz-veins traverse mica-schists and a small granite boss, forming a stockwork in the latter [74] The lodes contain cassiterite, mispickel, chalcopyrite, molybdenite, topaz and fluorspar, with wolfram in nests and bunches, and in single crystals up to 3 inches in length. At Villeray, in the same neighbourhood, similar veins are found, but carrying bismuth instead of tin. At Puy-les-Vignes, near St. Leonard in Haute Vienne, a quartz-vein rich in wolfram has been worked to some extent [75]. Near the villages of Chanteloube, Mazataud and Chabanne, about 20 miles from Limoges, wolfram occurs in pegmatites. At Meymac in Corrèze wolfram and scheelite are found with mispickel in the upper part of lodes which carry bismuth in depth. Some tantalum minerals also occur here. Wolfram is also recorded from several localities in Charente, Saône et Loire, Nievre and Allier, and scheelite from Framont in the Vosges and from St. Lary in Hautes Pyrénées. None of these occurrences appear to be of any importance, and the French production is small, averaging about 200 tons per annum.

Germany [76]

Wolfram has long been known to occur in some quantity in the tin district of the Erzgebirge, on the borders of Saxony and Bohemia. Here the ancient crystalline rocks are penetrated by great masses of quartz porphyry of Permian age,

and this again by somewhat later intrusions of granite in the form of bosses and domes. These masses are highly mineralised, as well as the surrounding rocks, and the quartz-porphyry especially is extensively converted into greisen, and penetrated by lodes and stringers carrying a great variety of ores The most important district is that of Altenberg and Zinnwald in Saxony, and Graupen in Bohemia. The production of the Zinnwald district for the years 1890–1905 averaged 37 metric tons per annun. At Altenberg the ores occur in the form of a stockwork in the quartz-porphyry, extending to a depth of about 750 feet, and at one time largely developed by open-cut workings. At Zinnwald lodes from 4 to 30 inches thick, in the granite, consist of quartz, felspar, lithia-mica, cassiterite, topaz, tourmaline, wolfram, scheelite, wulfenite, stolzite, molybdenite and uranium minerals, together with primary and secondary ores of copper, arsenic, lead, zinc and iron. On an average the lode-stuff contains about 0 2 per cent. of wolfram. The wolfram occurs in compact masses up to 100 lb. in weight, and also in single crystals of varying size, usually not more than half an inch long, scattered through the gangue.

In the Geyer district, N.W. of Annaberg, is a stockwork in granite with wolfram-bearing veins up to 3 inches wide occurring in groups, but most of the ore is in impregnation zones in the country rock adjoining these lodes. Wolfram also occurs still further to the S.W., in the neighbourhood of Johanngeorgenstadt and Eibenstock.

The occurrences in other parts of Germany appear to be of no practical importance. Wolfram is recorded with lead and zinc ores in the Neudorf-Strassberg lode series at Neudorf, in the Harz Mountains; also with molybdenite at Tirpersdorf, near Olsnitz in Voigtland, as well as in the magnetite lodes at Schmiedefeld in Thuringia.

In 1912, the last year for which official statistics are available, the output of tungsten ores for the Kingdom of Saxony was stated to be 101 tons, while no other German State appears to have produced any [77]. It is believed that the greater part of the German production of late years was obtained by working over the old tin dumps.

Imports of Wolfram Ore into Germany

In metric tons (2,204 lb.)

	1910.	1911.	1912.
From British countries			
United Kingdom	400	658	1,056
India	89	130	467
British Malacca	106	179	197
Australia	601	900	1,073
New Zealand	94	86	35
Other British countries	—	—	—
Total	1,290	1,953	2,828
From Foreign countries			
France	56	105	112
Austria-Hungary	22	12	84
Portugal	473	383	319
Spain	61	70	27
Turkey	—	13	54
Japan	28	18	53
Argentina	364	544	508
Bolivia	51	369	397
Brazil	39	20	—
Chile	20	30	50
Peru	26	2	25
Other foreign countries	61	195	77
Total	1,201	1,761	1,706
Grand total . . tons	2,491	3,714	4,534
Grand total . . £	249,100	371,450	453,450

Austria-Hungary

The chief producing region of the Austrian Empire is in the neighbourhood of Graupen in Bohemia. This is a direct continuation of the Zinnwald-Altenberg field, and no further description is necessary. It was reported that in 1917 some new mines were opened in the neighbourhood of Elbogen, in the extreme north-western corner of Bohemia, on the southern side of the Erzgebirge. No details as to development or production are available. Wolfram has also been found in small quantity near Felsöbánya, six miles E. of the well-known mining town of Nágybánya in Hungary. It occurs along with silver-lead, blende and a little gold, a rather unusual association.

The total Austro-Hungarian production for 1912 was officially stated as 66 tons. There is nothing to show whether these figures refer to crude ore or to concentrates [77].

Italy

An occurrence of scheelite in the Cagliari district of Sardinia has been described by Lovisato [78]. At the antimony mines of Su-Suergiu and Genna-Gureu the country rock consists of argillaceous and micaceous schists with intrusions of porphyry penetrated by veins of quartz up to 8 inches wide. These carry antimony ores above and scheelite below. The latter also occurs in a compact and granular form in depth. It appears to be abundant and of good quality.

Russia

Tungsten ores are found in a few localities in Russia. A mine at Baevka, in the Government of Perm, was said to produce 1 metric ton per month, and at Nerchinsk in Siberia, an output of 6 metric tons per month is recorded. An occurrence of scheelite with tin, magnetite and copper ores at Pitkàranta, to the north of Lake Ladoga in Finland, is of some scientific interest, since the mineralisation is due to the intrusion of granite into limestones [79]. The yield of iron, copper, tin and silver was at one time considerable, but the scheelite does not seem to have been of any economic importance.

ASIA

Siam

Tungsten and tin-ores are found in considerable quantity in the Siamese territory intervening between Burma and the Malay States. The export of ore from Bangkok is shown in the table. Wolfram is mined in the district of Nakawn Sritamarat, and in the Trang district in the Siamese Malay States; there is also a little scheelite. Along the Southern Railway promising lodes and alluvial deposits have been located. Large quantities of mixed tin and tungsten concentrates are obtained by sluicing and bucket-dredging, and shipped to the Malay States for further treatment. In the Lacon district of Siam the output is variously estimated to be from 350 to 600 tons per annum [80].

Exports of Wolfram Ore from Bangkok, Siam

In pikuls (133⅓ lbs.)

To :	1913–14.	1914–15.	1915–16	1916–17.
Singapore	—	148·7	—	—
United States	—	—	924·9	1,008·6
Japan	—	—	168	—
United Kingdom	8·8	—	—	51
Hong Kong	—	—	—	84
France	—	—	—	156
Italy	—	340·8	—	—
Total	8·8	489·5	1,092·9	1,299·6
Metric tons	0·5	30	66	79

TONKIN

Wolfram is said to occur with cassiterite and quartz in a stockwork in a granulitic formation on the flanks of the Pia-Ouac Mountain, in the N'Guyen Binn district, in the province of Cao Bang. The output at present is small.

CHINA

According to American Consular Reports a considerable trade in wolfram ores developed at Hong Kong in 1917, a large proportion of the ore being shipped to America. It is obtained mostly from alluvial deposits in the provinces of Kwantung and Hunan, but it is also being successfully mined in Hong-Kong territory. The methods employed are most primitive, the ore being transported on men's backs to the rivers and loaded into small junks, in which it is shipped to the ports. The ore is found both in veins and in alluvial deposits in Haifeng, Lufeng, Pu-ning, Kityang and Wuhua. The best occurrence seems to be in Wuhua, 50 miles north of Hopo, where wolfram occurs in large veins over 6 or 7 square miles of country. There is a large market in tungsten ore in Waichow, and the chief port of shipment is Swatow. China virtually began producing tungsten ore in 1914, with a small output; since then there has been a rapid increase, the yield in 1918 being over 4000 metric tons. Recent information seems to indicate that this field will provide a very notable addition to the world's supply, but development is considerably hampered by Chinese mining laws, which do not encourage the introduction of foreign capital.

Japan

From 1909 to 1913 the average annual output o and scheelite in Japan was about 240 tons. In 1ᵔᵀ' production was about 450 tons of 60 per cent. concentrates, but this figure has now been considerably increased, and great efforts are being made to increase the outputs from Japan itself and from the territories under Japanese control on the mainland. The principal tungsten mines of Japan proper are the Kiwada Mine in Yamaguchi Ken (output 40 tons per month), the Taketori Mine in Ibaraki Ken (10 tons per month), and several smaller concerns with a combined output of about 75 tons per month.

In 1916 Korea (Chosen) produced 670 tons of 60 per cent. concentrates, and ore was imported into Japan from the Chin Chow district, in the Kwangtung leased territory in Southern Manchuria. The total output of Japan, Korea and Manchuria in 1916 is stated to have been 1,150 tons.

AMERICA

United States

The tungsten ores of the United States are, with a few unimportant exceptions, confined to the Cordilleran region in the west, and seem there to be associated in origin with the Tertiary folding movements. Deposits of the metal are found in all the Western States with the exception of Wyoming, and these mineral-bearing regions comprise some of the most important producing areas of the world, more particularly the Atolia-Randsburg district of California and the neighbourhood of Boulder in Colorado. The minerals include both the wolfram series and scheelite, the latter being by far the most abundant, and it is a noteworthy fact that the scheelite more commonly occurs with gold ores, as at Atolia and Randsburg, while the minerals of the wolfram series are found in conjunction with silver deposits [82].

The ores for the most part are mined in quartz veins and pegmatite dykes, and the placer deposits derived from them; but in Nevada and Eastern California exploitation on a large

scale has begun of contact-metamorphic deposits, which are described as follows by Mr. F. L. Hess, of the United States Geological Survey:

"In the Great Basin region of the United States, a broad belt of limestones, extending from the north-western part of Utah westerly across the central and southern-central parts of Nevada, thence swinging southward along the Sierra Nevada and around its southern end, has been intruded by granites which have brought with them tungsten-bearing solutions from which scheelite has been deposited in the metamorphosed limestones. The deposits are as variable in composition and in size and distribution as are most contact-metamorphic deposits. In places they are largely iron-garnet with dark green epidote. In other places iron is much less in evidence, and the garnets are light coloured and the epidote is also very light coloured. Hornblende forms a large part of a few deposits, and in many others is nearly absent. The ore is 'patchy,' and although spots are rich, in general the WO_3 content ranges from 1 to 2 per cent. The tungsten mineral is invariably scheelite, generally white, although a little is glassy, some is dark grey, and much is yellowish. The scheelite particles range from microscopic size to masses 2 or 3 inches across. Some show crystal form and many show a rough tendency toward regularity of outline. The patches, although usually containing perhaps a few thousand tons of ore, may reach millions in the largest deposits. It is not yet practicable to give an estimate of the probable output from this form of deposit" [83]

The output of the United States for recent years is shown in the world's production table on p. 3.

As will be seen the production increased greatly in 1915 and 1916 during the tungsten boom, and that it has since fallen off; but, nevertheless, the United States remains the world's largest producer and bids fair to keep the position. The greater part of the output comes from Colorado and California, and that for the most part from the two districts above mentioned. After these come Nevada, Arizona and South Dakota, in comparison with which the production of all the other States is relatively small. The outputs of the

individual States for the years 1915–1917 have been as follow, in short tons (2,000 lb.)

State	1915	1916.	1917.
Alaska	2	50	35
Arizona	127	240	225
California	962	2,200	2,250
Colorado	963	2,401	2,707
Connecticut	1	3	—
Idaho	32	45	10
Missouri	—	2	50
Nevada	55	700	250
New Mexico	45	18	12
South Dakota	140	200	267
Utah	3	8	11
Washington	2	8	2
Total	2,332	5,875	5,819

The figures for 1915 are taken from the official Geological Survey returns, those for 1916 and 1917, with the exception of those for Colorado, are from the Mineral Industry, and, when added up, give a total somewhat in excess of the official figures.

Arizona.—Tungsten minerals are mined in Cochise, Pima and Santa Cruz Counties in the south, Yavapai County in the centre, and Mohave County in the north-west. In Cochise County the producing districts are situated in the Little Dragoon Mountains near Russelville, and in the Whetstone Mountains, 12 miles south of Benson. At the former locality, which is the most important in the State, the country rocks are crystalline schists and ancient sediments, invaded by granite that is cut by acid dykes. In 1916 the Primos Chemical Company, operating near Johnson, was concentrating per day 30 tons of quartzose ore, carrying hübnerite, wolfram and scheelite, and producing 60 per cent. concentrates [138] [84]. The ore in the veins which strike N. 40° E. is "bunchy," the "bunches" varying from a few pounds to 4 or 5 tons of 60 per cent. ore. Extensive placer deposits of coarse gravel were once mined, but these are now exhausted.

In the Whetstone Mountains [85] the American Tungsten Co. is working deposits of wolfram occurring in a large quartz vein and as segregations in granite.

In the Arivaca district of Pima County hübnerite is mined with wolfram and a little scheelite in quartz veins cutting granite country [86].

In Santa Cruz County at Calabasas, in the Nogales district near the Mexican border, low-grade deposits of wolfram and scheelite are found in quartz veins associated with lamprophyre dykes cutting granodiorite [87].

Tungsten ores occur with bismuth and tantalum in pegmatite belts in the Eureka, Tip Top, Tule Creek and Crown King districts of Yavapai County [88]. In Mohave County, in the Acquarius district, wolfram, and in the Yucca [86] district, wolfram and scheelite are mined in quartz veins in schist and granite country. In addition, mining is carried on at Camp Wood, 45 miles west of Prescott, Oracle, where gold and scheelite are mined together, Powers Gulch near Globe, and in other localities [89].

California.—Very large deposits of tungsten ores exist at several different localities in this State, near Atolia and Randsburg on either side of the boundary between San Bernardino and Kern Counties, and at other places in these counties, near Bishop in Inyo County, and in Grass Valley, Nevada County. The Atolia-Randsburg district is the most important of these, and is the largest producer of scheelite in the world. Several companies are at work here operating the Atolia, Osdick, Scheelite and other mines at Atolia, and a number of mines, including the Sunshine, at Randsburg [90]. The largest of these is the Atolia Mining Co. [91], whose mill has an annual capacity of 25,000 tons, and which in 1917 produced about 1,200 short tons of 60 per cent concentrates, amounting to one-half of the output of California [92]. The ore is mined in lodes and also in placers, which yield the majority of the ore produced. In the Atolia district the scheelite occurs, associated with fine-grained quartz and ferruginous calcite, in more or less continuous fissures in granite, sometimes associated with basic dykes, as replacement deposits in the country rock on either side of narrow veins, and also in contact-metamorphic deposits, accompanied by garnet, epidote and other metamorphic minerals in limestones at their contact with granite. The lodes, whether fissure veins or replacement bodies, may be as much as 3 feet wide, and have been followed down to a depth of 700 feet along the dip [86]. They carry very little pyrites, and the

gangue is mainly ferruginous calcite. This has been replaced by the scheelite, which often shows the structure of the primary mineral. The scheelite is very pure, the only impurity being silica, which was deposited along cleavage cracks in the original calcite [93].

The vein material is soft, and as the veins do not project above the surface, the outcrops are covered with desert debris, and are hard to find. In the Randsburg district and in other parts of Kern County, the scheelite is found mostly as bunches in the gold-quartz veins, and also as nearly pure stringers in slate, in quartz veins in granite associated with copper minerals, and also in pegmatites.

The mining was at first carried on in placers. In the Atolia district these are all residual desert deposits in which the scheelite is coated with calcium carbonate or caliche. They are very rich, and lumps of ore up to 100 lbs. in weight are found. In 1915, one section, the "Potato Patch," was employing fifty men and producing 300 lbs. of high-grade scheelite per day [90] Stream placers are also worked between Atolia and Randsburg at Baltic Gulch [82] As the country is desert, concentration is largely carried out by means of dry concentrators [94]. Up to 1915 water was carried by rail to the Atolia Co.'s mill for a distance of 50 miles; in that year, however, water was struck in a deep well at Randsburg, and is now piped from that place to the Atolia mill [89]

The lodes of Atolia seem to be continued eastwards toward Searles Lake, and, since similar conditions prevail in the eastern parts of San Bernardino County, it is inferred that the deposits will probably be found over the whole width of the county [95].

In the east near the Nevada boundary wolfram and scheelite are mined in the Clark Mountains, near Roach, by the Mohave Tungsten Company, which is operating two claims, one producing pure wolfram and the other pure scheelite [90], and also at other places in the Ivanpah, Kelso and Cima districts.

Inyo County.—Scheelite is mined at Deep Canyon, near Bishop, in the Owens Valley, in very extensive and very low-grade deposits in metamorphic limestone, forming the southern

end of the calcareous contact-metamorphic belt of the Great Basin region. The ore occurs in small particles in large masses of a dark-coloured metamorphosed limestone with garnet, epidote, quartz and other minerals, near the contact with granites [83 and 96]. It was first detected in washing placers for gold, and its occurrence in the limestone would have escaped detection had not special search been carried out. The content of the ore is sometimes as low as 0·5 per cent WO_3 [92], but the deposits are very large, and can be worked cheaply in open quarries.

Nevada County.—Tungsten ores are found in Grass Valley about 40 miles north of Sacramento. The tungsten mineral is chiefly scheelite, associated with gold, in quartz veins, which traverse a series of black slates, quartzites, amphibolite schists and diabase. The veins are productive only in the sediments, there being no scheelite in them where they cut the schist [97]. The scheelite is full of small stringers of quartz, from which it is separated with difficulty, so that, at the Union Hill Mine, the highest grade of hand-picked ore never rises above 67 per cent. WO_3. The ore contains gold, phosphorus, sulphur and arsenic, and is mined both in lodes and placers.

Colorado —The chief producing area of this State is situated near the border between Boulder County and Gilpin County, on a plateau at a height of about 8,200 feet, which rises to the continental divide to the west, and falls abruptly to the great plains on the east. The mines are mostly arranged along a belt, 12 miles long by 6 miles wide, following the Middle Boulder Creek, in west-east direction, between Nederland and Boulder City, but the mineralised region also extends to the south towards Beaver Creek and into Gilpin County, near Rollinsville [98]. The rocks of the district are quartz-mica-schist and granitic gneiss, invaded by pre-Cambrian granite, the whole assemblage being cut by a much later series of dykes which range from limburgite to granite-pegmatite. The tungsten ore, here almost entirely ferberite, is found in a group of veins, with a general S.W.–N.E. strike. To the north-west and south-west of this group of veins the country is intersected by gold-silver lodes, while to the east

it is barren [99]. The gold-silver lodes are partly sulphidic quartz veins and partly sheeted zones with gold tellurides. The ferberite veins are closely related to the latter, and occur in sheeted or crushed zones which are reticulated, and while the individual veins vary from a fraction of an inch to several inches wide, the ore-bodies may reach a width of 14 feet, as at the Philadelphia Mine of the Wolf Tongue Mining Co. [99]. The veins cut the granite, gneiss and pegmatites, though they are partly contemporaneous [100] with the latter, the age of which is probably Tertiary [101]. Most of the valuable deposits are found in the granite or along the granite-gneiss contact, few being found in the gneiss itself.

The Boulder tungsten veins are remarkable for the almost complete absence of the minerals usually associated with the ores of this metal. The gangue is very variable in character and amount; quartz is not common, its place being taken to a great extent by chalcedonic silica or "horn" and fragments of country rock. The fissures have in most cases been opened several times, so that both the ore and gangue are often brecciated [99].

The thin veins are often completely filled with ferberite, but, in the thicker veins, three distinct types of ore are found: (1) Well-crystallised crusts and layers of ferberite covering the surface of the rock and "horn" fragments, and cementing them into a rather open breccia (peanut ore). (2) Massive granular ore showing no crystal faces and occurring in the wider and less brecciated parts of the vein. (3) Highly siliceous ore in which the ferberite in fine grains is scattered through the "horn" [98].

The last type offers great difficulties in milling, since the fine crushing which is necessary increases the losses due to sliming to large proportions. Some of this ore, though quite black and looking like pure ferberite, may contain as much as 34 per cent. of silica, and the saving may be as low as 30 per cent. of the content [102].

The payable ore is generally confined to small lenses a few feet in length, though exceptionally they reach a length of 150 or even 200 feet [103]; the average content of the ore

is between $1\frac{1}{2}$ and 5 per cent. WO_3, though some is as rich as 50 per cent. WO_3.

The more important mines are grouped into three distinct districts: (1) The area north and west of Nederland [104], including the Conger properties, Sherwood Creek and Lakewood: (2) Stevens Camp to the east of Nederland: (3) Beavers Creek, south of Nederland, near the Gilpin County line.

In 1916 the Conger shaft was 1,100 feet deep, and the Beddig shaft 600 feet; but besides these there were no mines operating at greater depths than 300 feet, and it was considered that the field was only in a superficial stage of its development [103]. It has been shown since that the values do not persist in depth, but that there is a general tendency for the veins to thin out at a depth of 250 feet.

The output has fallen off very considerably in the last year or two; in the early part of 1916 it was never less than 250 tons of 60 per cent. concentrates, while in the first months of 1918 the figure was about 100 tons per month, most of which came from new mines [104].

The greater part of the output is now controlled by a few large companies, of which the Wolf Tongue Mining and Milling Co., the Primos Mining and Milling Co., the Vasco Mining Co., and the Boulder Tungsten Production Co. are the largest, but owing to the patchy character of the ore mining is carried on chiefly by lessees working on short leases [103].

Outside Boulder and Gilpin Counties, hubnerite is mined in San Juan County [98] and at Leadville in Lake County. Near the latter place hübnerite and scheelite occur on Breece Hill [105] in a contact-metamorphic deposit along the junction between grit and gray monzonite porphyry.

The tungsten minerals are found in a quartz gangue with auriferous pyrites, in lodes striking N. 33° E The workable portion is confined to an elliptical shoot 120 feet by 130 feet, and the values are known to persist to a depth of 900 feet.

Connecticut.—There is only one mine in this State, at Long Mountain, near Trumbull [106]. The ore-body takes the form of a blanket vein along the contact between marble and an epidiorite sill, carrying scheelite with a little wolfram. The ores

seem to be associated with later dykes, and a pegmatite dyke with ore of milling grade is situated elsewhere in the district. The deposit is of interest as being the only tungsten mine worked in the region of Appalachian folding.

Idaho.—Tungsten deposits are widely distributed throughout this State, though only three localities are of any economic importance. At the first of these, Murray in the Cœur d'Alene district [107] of Shoshone County, scheelite is found in the Golden Chest gold mine, in quartz veins traversing slate country. The tungsten ore is associated with gold, silver, lead and copper ores, and persists to a depth of 900 feet in the mine [86]. In 1916 placers were being prospected along Pritchard Creek, which flows past the mine [108].

In the Blue Wing district of Lemhi County hübnerite occurs on Patterson Creek with silver, lead, zinc, molybdenum and copper ores in quartz veins cutting Algonkian slates and schists [109]. At Nelson Prospect in Blaine County [90] wolfram is found in a vein of porphyry breccia cemented by narrow bands of quartz, along the contact between yellow porphyry and ancient limestone and quartzite.

Missouri.—There is only one producing mine in this State, the Einstein Mine; this is situated at Silvermine, about 10 miles west of Frederickstown, on the St. François River. The ore is wolfram, which occurs with galena and tetrahedrite in a fissure vein in granite. The mine was worked many years ago as a silver-lead proposition, and has now been reopened as a tungsten mine [110].

Montana.—Tungsten ores are reported from Butte and other places in this State, but the only deposits of any size are in the Potosi district, near Pony, where hübnerite occurs with fluorspar in argentiferous quartz veins cutting quartz monzonite [111]. The veins strike E and N. and may reach a width of 6 feet, with streaks of hübnerite-bearing quartz up to 18 inches wide. At one place they grade into pegmatite.

Nevada.—Till the year 1916 the tungsten output of Nevada was very small, but in that year the output increased substantially (see p. 61). The greater part of the output comes from White Pine County in the east and Humboldt County

in the north, though the ores are worked in most of the counties in the State [86].

The deposits of White Pine County are all found along the Snake Range, which runs north and south near the Utah border. They are situated chiefly on the western slope of the range over a distance of about 80 miles, from Cherry Creek, 50 miles north of Osceola, to the Minerva district, about 30 miles south of that town [89]. The ore occurs in quartz veins associated with a little fluorspar and pyrites in quartzites, argillites, limestones and old granites, which are invaded by a younger granite porphyry. The tungsten minerals are both hübnerite and scheelite, of which the latter more commonly occurs in limestone country, but both are sometimes found together in the same vein. The chief mining localities are Cherry Creek, in the north, Tungstonia, about 45 miles south-east of Ely, Scheelite, near Wheeler Peak, Tungsten, 12 miles south of Osceola, the Minerva district in the south where scheelite is mined, and Garrison and Camp Bonita on the eastern slope of the range [112]. The content of the ore is generally low except at Tungstonia, where hübnerite is mined in many veins, some of which are said to be from 15 to 30 feet wide. This is the richest hübnerite deposit in the United States, and these were the only mines working in 1917, when the others on the Snake Range were forced to close owing to the fall in prices [113].

In Humboldt and Elko Counties scheelite is mined in the contact-metamorphic belt in garnetiferous limestone, limestone and shale along the contacts with granodiorite. The producing localities are Toy, 18 miles south-west of Lovelocks, and the Ragged Top mines, 10 miles west of Toulon, in the Lovelocks district. The output of the Ragged Top mines in 1916 was 41 tons of 60 per cent. concentrates [86]. In addition to these localities, tungsten ores are worked in Mineral County at Douglas, and Sodaville near the California border, where the crude scheelite ore contains 4·2 per cent. WO_3, in Nye County at Round Mountain and Spanish Springs, where hübnerite is dry-washed from desert sands [90], and at various points in Eureka, Esmeralda and Lincoln Counties.

New Mexico.—There are several interesting occurrences in

this State, but the only appreciable output comes from the White Oaks Gold Mine [114], where hübnerite is found in a crushed zone in rhyolite and has been mined to a depth of 1,350 feet. Tungsten ores also occur at Gage in the Hachita district, in a limestone associated with quartz monzonite porphyry, at El Porvenir [115], where the ore is scheelite in pegmatite with fluorspar, molybdenite and copper ores, and at other localities.

South Dakota.—The tungsten deposits of this State are confined to the Black Hills, the two important areas being those of Hill City and Lead. At the former locality wolfram and cassiterite occur in pegmatite dykes, associated with veins and lenses of quartz, whose characteristics resemble those of the Cornish deposits. Most of the wolfram is associated with cassiterite in the pegmatites in shoots which generally extend across the vein [86].

The greater part of the output of the State comes from the Homestake and Wasp No. 2 mines near Lead. Here wolfram with a little scheelite is found in replacement deposits in a sandy dolomite [116] of Cambrian age, overlying an auriferous quartzite which rests on Algonkian schists. The ore-bodies are irregular tabular masses, containing quartz, fluorspar and other minerals about 2 feet thick, with an area of 20 or 30 square feet, and are associated with large flat masses of refractory siliceous gold ores.

Wolfram is also found at Pine Creek, Etta Knob, Nigger Hill [116], and other places in the Southern Black Hills. Ferberite occurs in pegmatites at Harney Peak [86].

Utah.—Tungsten ores have been discovered near Linwood [86], in the Uinta Basin, and in the Deep Creek Mountains and Grouse Creek Mountains in the north [115], in contact-metamorphic deposits which form the north-east end of the contact-metamorphic limestone belt of the Great Basin.

Washington.—A few small shipments of ore are reported from different places in the Cascade Range [86], but the producing areas of the State are situated in the north-east at Tungsten Mountain, near Cathedral Peak, 45 miles north-west of Oroville [89], and at Cedar Canyon [117] and Big Blue Grouse Mountain [118], near Loon Lake in Stevens

County. At Cedar Canyon the ore is hübnerite, while at Big Blue Grouse Mountain it is wolfram, and occurs in quartz veins and lenses in schists and shales invaded by granite. Before the war a fairly large quantity of concentrates was reported to have been sent to Germany from the Germania Mine at Cedar Canyon, but the output of recent years has been small.

Alaska.—Tungsten ores occur at several places in this territory, but the only deposits of economic value are situated at Fairbanks [119] on the Tanana River, and at Nome on the Seward Peninsula. At Fairbanks scheelite is found in gold placers and in shoots and lenses along the junction between crystalline limestone and mica-schist, which are invaded by quartz-diorite. The scheelite is deposited irregularly through the shoot in grains up to the size of a pea. Early in 1918, 265 tons of ore had been shipped. At Nome [120] scheelite is mined in gold placers. It is also reported from Birch Creek, and, together with wolfram, at other places on the Seward Peninsula.

Mexico

Tungsten minerals have been reported from two or three places, but the only deposit of economic importance is the Yaqui River in Sonora, which in 1915 exported over 100 tons of scheelite concentrates to the United States [89]. Wolfram occurs with topaz in the neighbourhood of Durango [121]. The veins fill contraction fissures in Tertiary volcanic rocks.

Argentina

The tungsten region of Argentina in confined to the Pampa Range, which runs almost north and south between latitudes 25° and 35° south, and is about 250 miles east of the Andes. The chain is situated partly in the province of Catamarca in the north, and in the provinces of Cordoba and San Luis in the south, where it divides into the Sierra de Cordoba and the Sierra de San Luis, in which ranges the most important mines are situated [122]. Geologically the range is composed of granitic gneiss and schists striking north and south with

a westerly dip. These old rocks were invaded at some later time by granites accompanied by tourmaline-bearing pegmatites and veins and lenses of quartz, carrying ores of tungsten and other metals, and a later series of barren quartz veins. The pegmatites, which carry no metallic minerals, generally follow the direction of the strike of the schists, as do the barren quartz veins, while the productive veins, with very few exceptions, run east and west across the line of strike, and dip to the north. They are found in the schist, gneiss, and in the granite near its contacts. The ore is chiefly wolfram, with a little scheelite, hübnerite and tungstic ochre accompanied by pyrites, copper ores, galena, bismuthinite, a little molybdenite, occasionally cassiterite, and, in some places, notable amounts of niobium and tantalum minerals. The gangue is mainly quartz, sometimes with white mica and occasionally topaz and fluorspar. The ore-content is, as a rule, between ½ and 1½ per cent. of wolfram, which is generally irregularly distributed in large crystals, often perpendicular to the walls of the veins, and also in nests, which at Los Condores Mine are sometimes as large as 5, 10 or even 13 tons in weight, though nests of 2 or 3 tons are rare at most of the mines. In the majority of the occurrences the values are good in the upper parts of the veins, but fall off in depth, often reaching an unpayable figure at a depth of about 60 feet. The veins are sometimes brecciated and, where this has occurred, enrichment has often taken place.

The principal mining localities are Cajon, Gualapaji, Amboti, Incasti, Colorados and Mazan in the province of Catamarca, the Anti and Brillante Mines near Guasapampa, Quines, San Ramon and Pantana, San Ignacio, El Morro, and, in the district of Concoran in the south, Los Condores, Pisco Yacu and Cumbre.

The only mine of great importance is that of Los Condores, which, together with those of San Ramon, Puntana, Cumbre, San Ignacio and Brillante, is controlled by the Hansa Sociedad de Minas, which, in its turn, was controlled by Krupps At this mine the lode is vertical in the granite-gneiss contact, striking east and west; it is about 5 feet wide, containing 1 to 4 per cent. WO_3 with niobium and tantalum, and can

be traced between 1,500 and 2,000 yards, of which at least 600 yards are workable. It is brecciated and composed of anastomosing veins. The lode crops out on the side of a hill and is worked by adits. At the level of the main adit it is displaced by a series of step faults which necessitate frequent cross-cutting. The ore has now been exhausted down to this level, and the mine is being further developed by a shaft sunk to a depth of 300 feet. The output is about 40 tons of 60 to 65 per cent. concentrates a month, the total output of the mines of the Hansa Sociedad being 50 tons a month.

The Cumbre mines, near Concoran, have very high-grade ore in veins traversing granite and gneiss, but are unprofitable owing to the lack of timber and transport.

The Minas Brillante, near Guasapampa, include four mines. The veins are horizontal in gneiss and granite and crop out like beds on the hill sides, with the exception of one which strikes S.S.E.–N.N.W. and dips 30° to S.S.W. The veins are much divided in places, and vary in thickness from fractions of an inch to 2 feet 8 inches. The gangue is hard quartz, with very little mica and traces of copper and iron. The tungsten mineral is wolfram, disseminated through the veins, large lumps being rare. The ore content is very variable, and the mines are poor despite a large number of lodes.

In the Auti district of the Sierra de Guasapampa both vertical and bedded veins occur over a length of 3 miles in granite and gneiss. They contain wolfram with scheelite and tungstic ochre, associated with tourmaline, mica and copper ore. The ore is of poor quality. The veins often split up and thin out in the gneiss and at a depth of 50 feet in the granite.

The Colorados Mine is remarkable for the fact that the wolfram is found in an aplite vein along a granite-gneiss contact. The vein is about 16 inches wide and carries about 1½ per cent. of wolfram with copper pyrites, bismuthinite and molybdenite, the last in payable quantity

The Mazan Mine, about 21 miles north of the town of La Rioja, is the only place in the region where wolfram and cassiterite are worked in the same mine The minerals are

so coarse that 65 per cent. concentrates can be obtained by hand-picking. The mine is worked by a French company.

Other foreign companies in Argentina are an English company which is working the Pisco-Yacu Mine, and an American company which is operating that of El Morro. At the latter mine the ore is found in shoots in micaceous quartz veins in schists, associated with aplite and pegmatite dykes and granite; the veins, which are from 2 to 4 feet wide, strike N.N.E. and carry 1 to 1·25 per cent. WO_3 in their richer portions [104].

The output of Argentina is now almost entirely exported to the United States. Prior to 1914 it was all shipped to Germany, and on the outbreak of war most of the mines were closed. The great rise in prices in 1915, however, caused them to re-open, and in 1916 the exports were again normal. The outputs during recent years are given on p. 3.

PERU

The Peruvian deposits are, with one exception, situated near the valley of the Chuquicari, on the Pelagatos and Tamboras Mountains, in the departments of Ancachs and Libertad [123]. These districts are both approached from the port of Chimbote, whence they are distant about 142 miles, of which only 48 are served by a railway [124]. From published information, the largest deposit is that of Huaura Mountain, in the Pelagatos Mountains, which was till recently under control of C. Weiss & Co of Lima [125]. In addition, there are three other companies operating in this region and two on the Tambora Mountains [124] All these properties are situated at great heights, between 13,000 and 14,000 feet above sea-level The ore is chiefly hübnerite with some wolfram, in quartz veins, which also contain varying amounts of pyrites, grey copper and galena, and sometimes gold and silver values The average content of the ore is between 1 and 2 per cent. WO_3, with often 25 to 30 per cent. of copper and 25 oz. of silver to the ton Though ample water-power is available, and some of the mines have installed machinery, the mining has generally been conducted by very

primitive methods, and only about 50 per cent. of the values have been saved.

On Mt. Huaura [125] sandstones and slates have been invaded by a granite boss which has caused a considerable amount of metamorphism along the contacts, forming a mineralised aureole, while the intrusive rock assumes the character of a gneiss. The Pelagatos River has cut a deep valley through the boss exposing the contact, along which hübnerite deposits are found on both sides of the stream. The most important are two large quartz veins, between 5 and 25 metres thick, which crop out on the slopes of Mt. Huaura through a mass of sediments which have been enclosed in the granite. The hübnerite is found in nests along the hanging and foot-walls of the veins, together with pyrites, grey copper and galena in a gangue of quartz and fluorspar, the fluorspar and the hübnerite occurring in crystals of large size.

It was estimated by Tarnawiecki that between 6,000 and 7,000 tons of 60 per cent. concentrates could be obtained from this mine yearly, but this has not been realised, the actual output being 15 tons per month. In 1916 a British syndicate obtained an option to work it on a large scale, but no information as to the results obtained is yet available [124].

The ore from the other mines in the Pelagatos and Tamboras Mountains seems to be of similar character except for the occurrence of tetrahedrite at the latter locality.

Tungsten ores were reported to have been discovered in 1914 in the department of Tayabama [126], and deposits have been described near Lircay in the department of Huancavelica [127]. Here wolfram occurs in radiating aggregates in a gangue of ferruginous quartz, with pyrites and a little gold, in two lodes cutting diorite country. There have been no returns from this mine of recent years, and it appears to have been abandoned.

Other deposits have been discovered recently in the neighbourhood of Tarica [128]. The mineralised area measures 4 miles by 2½ miles, in which 15 veins have been discovered of an average width of 50 centimetres and containing about 3 per cent. WO_3. The mineral is ferberite in a quartz gangue.

The outputs of tungsten ore in Peru during recent years are given on p. 3.

Chile

In this country tungsten deposits are located in the province of Tacna [129], not very far from the port of Arica, on the River Lluta. In 1900, 125 tons of concentrates were shipped, but the output fell off and no returns have been made in recent years.

Bolivia

The Bolivian tungsten deposits are all situated on the Cordillera Real and Eastern Cordillera [130], which lie east of the main chain of the Andes and are divided from it by a high plateau some 150 miles broad. The deposits occur principally in the departments of La Paz, Oruro and Potosi, the most important districts being Quimza Cruz, north-west of Cochabamba, and the region between Uyani and Chorolque, in the south of the department of Potosi, in which Sala Sala is the chief centre [131]. The deposits are found all along the Eastern Cordillera and persist to the south into its southern continuation, the Pampa Range in Argentina. The country rock consists of palæozoic sediments and granites. The ores, which include wolfram, hübnerite and scheelite, occur in quartz veins associated with mispickel, pyrites and tin, bismuth, silver and copper minerals and, like those of Argentina, are often accompanied by considerable quantities of niobium and tantalum. The values as a rule do not seem to persist in depth.

Reports as to the content of the ores are conflicting, and while some authorities say that they are mostly of low grade [90], others quote values from 5 to 37 per cent. of metallic tungsten [132]. It is to be supposed that these high figures apply to hand-picked ore.

Many of the mines are situated at great heights, up to 16,000 feet, and they suffer greatly from inaccessibility and lack of capital for development [132]. Mining and concentrating methods are usually very primitive, the greater part of the concentration being carried out by hand-picking [90].

Though there are about ninety mines in all [132], the output is variable; and while, during the first three months of 1916, 792 metric tons were produced, for the remainder of the year the production was only 107 metric tons [133]. The output is divided up between the departments as follows: Oruro 70, La Paz 20, and Potosi 10 per cent Of the portion exported, 75 per cent. went to the United States and 25 per cent. to Europe, but large quantities are reported to have been stored up in the country till the close of the war. Most of the ore is shipped to Antofagasta, since that Chilean port is in railway communication with Oruro and La Paz. The outputs during recent years are given on p. 3.[1]

BRAZIL

Tungsten is reported from many districts in Brazil, but the only mines at present being worked are those of Encruzilhada, in the State of Rio Grande do Sul, where wolfram is found together with tin over an area of about 20 square miles. It has been reported that these deposits are very rich and important, but the output never seems to have been very large, though before the war exports were made to Krupps through Porto Alegre [134]. Tungsten ores are found at other places in this State and also in the States of Espirito Santo and Minas Geraes [90], but at none of these localities are they being exploited. In 1908 Brazil exported 16 tons of concentrates [89], but no returns of output are available after that date.

[1] While these sheets were passing through the press further information on the tungsten ores of Bolivia has been given in a paper by Mr. G. F. J. Preumont [137], in which he states that the output for the years 1916 and 1917 was much greater than that given in the table (2,986 long tons in 1916 and 3,828 long tons in 1917). The larger portion of this output came from the departments of La Paz and Oruro, the principal fields in the former being Palca and Inquisiri and Carde Anque in the latter.

The production for 1916 is divided as follows:

	Long tons
La Paz	1,494·0
Oruro	936·6
Potosi	332·6
Cochabamba	2[illegible]2·8
	2,[illegible]·0

REFERENCES TO LITERATURE ON TUNGSTEN

The Publications are referred to by Numerals in the Text

[1] Bulletin No. 582 of United States Geological Survey, 1914. Colorado Ferberite and the Wolframite Series. (Hess and Schaller.)

[2] Records of the Geological Survey, New South Wales, 1916, **9**, 171. Notes on Chillagite.

[3] Geological Magazine, 1918, pp. 193, 241, 293, 367. The Genesis of Tungsten Ores. (Rastall.) Abstract in Mining Journal, 1918, **122** 564, 581, 597, 608.

[4] Tungsten Ores in the Malay Peninsula, 1916 (Scrivenor.) Lecture delivered at Tavoy, etc. Rangoon, 1918. (Jones.) Reprinted in Mining Journal, 1918, **120**, 135.

[5] Mining Magazine, 1915, **12**, 351. (Taylor.)

[6] Mining Journal, 1916, **115**, 779 and 797.

[7] Die Metallurgie des Wolframs, Berlin, 1911, pp. 267–86. (Mennicke.)

[8] Mining Journal, 1918, **122**, 522–5. (Keenay.)

[9] Journal Iron and Steel Institute, 1903, **64**, 14. (Hadfield.)

[10] Report of Departmental Committee on Engineering Trades after the War (Cd. 9073), 1918, pp. 34–6.

[11] Mining Journal, 1917, **116**, 20. (Bellis and Hardy.)

[12] Steel and its Heat Treatment, New York, 1918. (Bullens.)

[13] Engineering and Mining Journal, 1918, **105**, 997. (Haynes.)

[14] Engineering, 1917, **104**, 128. Metall und Erz, 1917, p. 21.

[15] Mining Journal, 1913, **101**, 578.

[16] Berichte der deutschen chemischen Gesellschaft, 1882, **15**, 499. (Philipps.) Zeits. anorg. Chemie., 1903, **37**, 125. (Engels) Ibid., 1904, **38**, 148. (Schafer.)

[17] Transactions of the Royal Geological Society of Cornwall, 1912, **14**. Observations on the West of England Mining Regions. (Collins.)

[18] Memoirs of the Geological Survey. Second Edition, 1916. Special Reports on the Mineral Resources of Great Britain. Vol. I. Tungsten and Manganese Ores.

[19] Geology of the Land's End District. Mem. Geol. Surv., 1907, p. 48.

[20] The Geology of Falmouth and Truro. Mem. Geol. Surv., 1907, pp. 209, 220.

[21] Mining Magazine, 1917, **16**, 345. (Maclaren.)
[22] Mining Journal, 1917, **116**, 151.
[23] The Geology of Bodmin and St. Austell. Mem. Geol. Surv., 1909.
[24] Quarterly Journal of the Geological Society, 1903, **59**, 142. (Scrivenor.)
[25] Mining Mag., 1918, **19**, 268.
[26] Quart. Journal Geol. Soc., 1908, **64**, 384. (Barrow).
[27] Geol. Mag., 1910, p. 19. (Finlayson.)
[28] "The Face of the Earth" (Suess, translated by Sollas), 1904, **1**, 451–7.
[29] Records of the Geological Survey of India, 1913, **43**, 48. (Bleeck.) Transactions of the Institution of Mining Engineers, **49**, 628. (Charter.) Transactions of the Institution of Mining and Metallurgy, 1916, **25**, 83. (Maxwell Lefroy.) Eng. and Min. Journ., 1915, **99**, 684. (Maxwell Lefroy.) Mining Mag., 1917, **17**, 60. (Griffiths.)
[30] Rec. Geol. Surv. India, 1913, **43**, 62. (Bleeck.)
[31] Lectures delivered at Tavoy, etc. Rangoon, 1918, pp. 55–70. (Coggin Brown.)
[32] Lectures delivered at Tavoy, etc. Rangoon, 1918, p. 23. (Marks.)
[33] Trans. Inst. Min. Eng., 1915, **49**, 628. (Chater.) Bulletin Imperial Institute, 1918, **16**, 76. (Adamson.)
[34] The Times Engineering Supplement, June, 1918.
[35] Quart. Journ. Geol Soc., 1916, **72**, 165. The Origin of the Secondary Stanniferous Deposits of the Kinta District, Perak. (Jones.)
[36] Paper on Tungsten Ores read before the F.M.S. Chamber of Mines at Ipoh, March 25, 1916. (Scrivenor.) Summary in Mining Mag., 1916, **14**, 347. F.M.S. Chamber of Mines Magazine, No. 4, September 1917.
[37] Mining Journal, 1917, **119**, 657.
[38] Mining Mag., 1918, **19**, 181.
[39] Mining Mag., 1915, **13**, 263. (Brelich.) Mining Mag., 1917, **17**, 179 and 211.
[40] Journ. Roy. Soc N.S.W., 1911, **45**, 1–60. (David.)
[41] Queensland Geological Survey Publications, 1915, **251**. Wolfram Mines of Mt. Carbine. (Ball.)
[42] Mining Journal, 1917, **119**, 607.
[43] Queensland Geol. Surv. Report, 1904, **188**, 6–14. Wolfram and Molybdenite Mining in Queensland. (Cameron.)
[44] Mining Journal, 1917, **119**, 745.
[45] Queensland Geol. Surv. Publications, 1915, **248**. The Wolfram, Bismuth and Molybdenite Mines of Bamford (Ball.)
[46] New South Wales Mineral Resources, 1911, **15**. Tungsten Mining in New South Wales. (Carne.)
[47] Mining Mag., 1918, **19**, 258–9.

[48] Annual Report Dept. Mines, New South Wales, 1915, p. 53.
[49] Bull. Geol. Surv. Victoria, No. 34, 34. (Harman.)
[50] Records Geol. Surv. Victoria, 1917, **4**, Pt. 1, 19.
[51] Victoria Year Book, 1905, Pt. 9. Economic Minerals and Rocks of Victoria. (Kitson.)
[52] Annual Report Dept. Mines, Victoria, for 1915, p. 49.
[53] Geol. Surv. Tasmania, Min. Res., 1916, **1**, Pts. 1, 2 and 3. (Hills.)
[54] Review of Mining Operations in the State of South Australia, 1916, **24**, 39.
[55] Bull. Northern Territory, 1916, No. 15*a*. (Gray and Winters.)
[56] Bull. Imp. Inst., 1909, **7**, 180.
[57] Bull. Northern Territory, No. 21, 1916. (Oliver.)
[58] Northern Territory Report of Administrator, 1915–17, p. 19.
[59] West Australia Geol. Surv. Bull. No. 30, 1907, pp. 115–17. (Simpson and Gibson.)
[60] Trans. N.Z. Inst., 1907, **40**, 110. (Finlayson) Proc. Aust. Inst. Min. Eng. N.Z., 1916, **21**, 37. (Gudgeon.)
[61] Bull. Imp. Inst., 1915, **13**, 252.
[62] Southern Rhodesia Geol. Surv. Report for 1917, Salisbury, 1918, p. 3. S. Rhod. Geol. Surv., 1918, Short Report No. 4. Tungsten Ores in Southern Rhodesia. (Maufe.)
[63] S. Rhod. Geol. Surv. The Tungsten Deposits of Essexvale, Umzingwane District. Reprinted from the Bulawayo Chronicle, May 18, 1917. (Zealley.)
[64] Geol. Surv. Canada. Summary Rept., 1909, p 228, and 1916, pp. 247–54. Tungsten Ores of Canada. Ottawa, 1909. (Walker.)
[65] Geol. Surv. Canada. Summary Rept., 1916, p. 247.
[66] Geol Surv. Canada. Summary Rept., 1916, p. 16.
[67] Handbuch der regionalen Geologie, **3**, Pt. 3. La Peninsule ibèrique. (Douvillé.)
[68] Bull. Soc. Ind. Min. Series (IV), 1911, **15**, 268. (Lozano.)
[69] Metall und Erz, 1914, **11**, 297. (Doerpinghaus). Mining Journal, 1917, **119**, 717.
[70] Revista Minera, 1913, p. 502. (Sacristan.) The Mineral Industry, 1913, **22**, 765. (Fink.) Eng. and Min. Journ., 1914, **97**, 27. (Sacristan, translation.)
[71] Mining Journal, 1917, **119**, 717.
[72] Eng. and Min. Journ., 1918, **106**, 48 (with map). (Foote and Ransom.) Mining Mag , 1916, **14**, 19. (Down.) Ann. Soc. Geol. Belge, 1909, **36**, 180. (Bronckart.) Mining and Engineering World, 1913, **38**, 677. (Ackerman.)
[73] Eng. and Min. Journ., 1917, **104**, 1109.
[74] Minéralogie de la France, 1910, **4**, 287. (Lacroix.)
[75] Bull. Soc. Ind. Min., No. 9, pp. 99–115. (Huré.)
[76] Ore Deposits (Beyschlag, Krusch and Vogt), translated by Truscott, 1914, **1**, 429. Die nutzbaren Mineralien im

deutschen Reiche, 1906, p. 566. (Bruhns.) Zeit. f. prakt Geol., 1907, **15**, 37. (Beck.)
[77] Mines and Quarries, General Report for 1912, Part IV (Cd. 7732).
[78] Atti R. Acc. dei Lincei, 1907, Series 5, Rendiconti, **16**. pp. 632–8.
[79] Bull. Com. Géol. Finlande, No. 19, 1907. (Trüstedt.)
[80] Commerce Report United States, No. 142, June 18, 1918.
[81] Commerce Report United States, No. 157, July 6, 1918. The Times Eng. Supplement, June, 1918.
[82] U.S. Geol. Surv. Bull. No. 652, 1917, pp. 36–44. (Hess.)
[83] Private communication from F. L. Hess.
[84] Eng. and Min. Journ., 1904, **77**, 263–5. (Rickard.)
[85] U.S. Geol. Surv. Bull. No. 380, 1909 pp. 164–5. (Hess.)
[86] Mineral Industry for 1916, **25**, 723–31.
[87] U.S. Geol. Surv. Bull. No. 430, 1910, pp. 164–6. (Hill.) U.S. Geol. Surv. Bull. No. 582, 1915, pp. 353–5. (Schrader and Hill.)
[88] Eng. and Min. Journ., 1916, **101**, 680. (Wolf.)
[89] U.S. Geol. Surv. Min. Res., Pt. 1, 1915, pp. 825–7.
[90] Mineral Industry for 1915, **24**, 687–97.
[91] Eng. and Min. Journ., 1917, **103**, 39.
[92] Discussion before U.S. Tariff Commission. Min. Journ., 1918, **122**, 461.
[93] U.S. Geol. Surv. Min. Res., Pt. 1, 1909, 577. (Hess.)
[94] Eng. and Min. Journ., 1916, **102**, 313.
[95] Eng. and Min. Journ., 1917, **104**, 939.
[96] Eng. and Min. Journ., 1916, **102**, 296. (Wittich.)
[97] Mining and Scientific Press, 1916, **112**, 40. (Macdonald.)
[98] Proceedings Colorado Scientific Society, 1909, **9**, 181–216 (George.)
[99] U.S. Geol. Surv. Bull. No. 583, 1914, p. 9. (Hess and Schaller.)
[100] U.S. Geol. Surv. Bull. No. 652, 1917, p. 77. (Hess.)
[101] U.S. Geol. Surv. Bull. No. 620, 1916, p. 311. (Hill.)
[102] Proc. Colo. Sci. Soc., 1909, **9**, 131–53. (Hills.)
[103] Eng. and Min. Journ., 1916, **102**, 165. (Wolf and Barbour.)
[104] Min. and Sci. Press (Feb.), 1918, **116**.
[105] Economic Geology, 1916, **11**, 30. (Fitch and Loughlin.)
[106] U.S. Geol. Surv. Bull. No. 213, 1903, p. 98. (Hobbs.)
[107] U.S. Geol. Surv. Prof. Paper No. 62, 1908, pp. 103, 143. (Ransome and Calkins.)
[108] Eng. and Min. Journ., 1916, **102**, 115.
[109] U.S. Geol. Surv. Bull. No. 528, 1913, pp. 73–4. (Umpleby.)
[110] Eng. and Min. Journ., 1917, **103**, 21. (Wheeler.)
[111] U.S. Geol. Surv. Bull. No. 574, 1914, p. 125. (Winchell.)
[112] Mineral Industry for 1915, **24**, 693. U.S. Geol. Surv. Bull. No. 652, 1917, p. 31. (Hess.)
[113] Eng. and Min. Journ., 1917, **104**, 1020.

[114] Min. and Eng. World, 1916, p. 1047. (Taft.) Mineral Industry for 1916, **25**, 731. (Fink.)
[115] U.S. Geol. Surv. Bull. No. 652, 1917, pp. 31–8. (Hess.)
[116] U.S. Geol. Surv. Prof. Paper No. 26, 1904, p. 164. (Irving.) U.S. Geol. Surv. Bull. No. 308, 1909, pp. 149–58. (Hess.)
[117] U.S. Geol. Surv. Bull. No, 550, 1914, pp. 29, 111–23, 130–3. (Bancroft.)
[118] U.S. Geol. Surv. Bull. No. 430, 1910, pp. 214–6. (Bancroft.)
[119] Econ. Geol., 1918, **13**, 112. (Bateman.)
[120] U.S. Geol. Surv. Bull. No. 358, 1908, pp. 38, 55–58. (Knopf.)
[121] Trans. Amer Inst. Min. Eng., 1898, **27**, 428. (Ingalls) Ibid., 1902, **32**, 506. (Aguilera)
[122] Zeit. f. prakt. Geol., 1909, **17**, 156. (Keyserling.) Mining Mag., 1918, **18**, 230.
[123] Mining Journal, 1914, **107**, 1009
[124] Bol. Cuerpo Ing. Min. del Peru, 1918, **80**, 74–6.
[125] Mining Journal, 1911, **94**, 687–9. (Tarnawiecki.)
[126] Mineral Industry for 1914, **23**, 753. (Fink.)
[127] Bol. Cuerpo Ing Min. del Peru, 1904, No. 11, p.31 (de Habich.)
[128] Bol. Cuerpo Ing. Min. del Peru, 1918, No 90, p. 43. (Yañez Leon.)
[129] Min. Journ., 1916, **115**, 832. (Ossa.)
[130] Eng. and Min. Journ., 1913, **96**, 636–8.
[131] Eng. and Min. Journ., 1916, **102**, 1006. (Singewald and Miller.)
[132] Eng. and Min. Journ, 1914, **97**, 1251. (Wepfer.)
[133] Eng. and Min. Journ., 1916, **102**, 464.
[134] Min. and Sci Press, 1917, **115**, November 10.
[135] Min. Mag., 1919, **20**, 76–89 (Campbell.)
[136] Econ. Geol., 1919, **14**, 68–78. (Gannett.)
[137] Bull. Inst. Mining and Metallurgy, No. 175, 1919. (Preumont.)
[138] Min. and Eng. World, 1916, **45**, 143. (Scott.)

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